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A MATHEMATICAL MODEL FOR EVALUATING ON-SITE SOIL EROSION

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Prepared for

USDA FOREST SERVICE
ROCKY MOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
Flagstaff, Arizona

Prepared by

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

R. M. Li
D. B. Simons
R. K. Simons

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February, 1977

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AUTHORIZATION

This research was sponsored by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station and supported with Colorado State University matching funds. The investigations were conducted in accordance with the Research Agreement No. 16-633-CA between the Rocky Mountain Forest and Range Experiment Station and Colorado State University. D. Ross Carder was the authorized project leader for the Rocky Mountain Forest and Range Experiment Station and Daryl B. Simons and Ruh-Ming Li were the principal investigators for Colorado State University. The period of agreement was from June 15, 1976 to March 31, 1977.

In accordance with the study plan, the report on the mathematical model for evaluating on-site erosion is submitted.

LIST OF VARIABLES

a	space weighting factor
a_2	coefficient in f vs. N_r relationship
a_3'	parameter dependent on soil characteristics in soil detachment relationship
$a(m,t)$	error component amplitude
a^*	two grain diameters above the bed
b	time weighting factor
B_1	constant dependent on roughness in velocity profile equation
b_2	exponent in f vs. N_r relationship
b_3'	exponent in soil detachment relationship
C	sediment concentration (by volume)
C_{a^*}	sediment concentration at a distance a^* above the bed
C_ξ	sediment concentration at a distance ξ above the bed
C_c	canopy cover density
C_g	ground cover density
C^p	potential sediment concentration
D	total amount of detached soil
D_f	detachment coefficient dependent on soil erodibility
D_r	potential rate of soil detachment by raindrop impact
d_s	sediment size
f	Darcy-Weisbach friction factor
f'	overall resistance factor
$\overline{f}$	average infiltration rate
F	infiltrated volume
ΔF	change in infiltrated volume
F_{ai}	adjusted percentage of sediment in the ith size fraction

F_i	original percentage of sediment in the ith size fraction
g	acceleration of gravity
G	ratio of a*/y
I	rainfall intensity (hyetograph)
i_e	rainfall excess
j	subscript denoting space coordinate
J_1	integral defined by Einstein
J_2	integral defined by Einstein
K	hydraulic conductivity
K_o	parameter describing grain resistance only
K_1, K_2	parameters describing overall resistance
K_r	parameter dependent on raindrop velocity
L	length of soil plot
n	superscript denoting time coordinate
N_r	flow Reynolds number
q	discharge per unit width
q_b	bed load transport rate
q_c	sediment transporting capacity
q_s	sediment transport rate (by volume)
$q_{s\ell}$	suspended load transport rate
q_t	total sediment transport rate
q*(x,t)	true discharge per unit width
r	variable
S_f	friction slope
S_i	initial degree of saturation of the soil

S_o	bedslope
S_w	degree of saturation of the soil after wetting
t	time
Δt	time increment
u_*	shear velocity
u_ξ	velocity at a distance ξ above the bed
V	mean velocity of flow
V_c	potential volume of canopy cover interception
V_g	potential volume of ground cover interception
V_i	total intercepted volume of rainfall
v_s	settling velocity of a sediment particle
w	parameter dependent of settling velocity
x	downslope distance
Δx	space increment
y	depth of flow
$y^*(x,t)$	true depth of flow
Z	net depth of loose soil
Z_i	amount of loose soil in the ith size fraction
Z_m	maximum penetration depth of raindrop impact
Z_w	depth of water plus loose soil
ΔZ^p	potential change in loose soil storage
α	coefficient in y vs. q relationship
α'	parameter dependent on soil properties and degree of saturation
β	exponent in y vs. q relationship
γ	specific weight of water
γ_s	specific weight of sediment

δ	error free factor
δ_s	constant in critical tractive force equation
ϵ	error tolerance
ξ	distance above the bed
$\xi(x,t)$	error in $y(x,t)$
$\eta(x,t)$	error in $q(x,t)$
η_s	roughness height
θ	ratio of $\Delta t/\Delta x$
ν	kinematic viscosity of water
ρ	density of water
σ	ratio of ξ/y
τ_c	critical tractive force
τ_o	boundary shear stress
ϕ	soil porosity
ψ_{ave}	average suction head across the wetting front
Ω	quantity made up of known discharges

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I. INTRODUCTION

GENERAL

As population increases, the development of water and land resources continues to grow. The population growth causes increased demands for recreation sites, housing, water, timber, energy and mineral resources. The need for housing and other resources has promoted numerous construction and resource acquisition activities that negatively infringe on the natural landscape. This infringement often takes the form of some types of landscape modification including changing of slope gradients, removal of native vegetation, increased construction of roadways, alteration of drainage patterns, and disturbing the top soil. All of these landscape infringements can act singularly or jointly to change the water and sediment yield from a given site. Because most of the forest lands are located in the headwater regions of streams, significant quantities of sediment delivered to the channels may cause adverse impacts on aquatic and riparian systems, reduce channel capacity, and increase flood hazards. An adequate sediment control can effectively reduce sediment yields and decrease erosion impacts on the downstream channels. Without methods to accurately and reliably predict watershed response, planners cannot quantitatively evaluate alternative management practices.

The evaluation of alternative erosion control measures requires a proper method of estimating on-site soil erosion from treated and untreated surfaces. The available methods for estimating on-site soil erosion are mainly dependent on statistical analyses of observed data from experimental plots or natural watersheds. A model with physical significance appears to be more useful than those based upon regression analysis when estimating time-dependent erosion rates.

SCOPE OF STUDY

In this report, an unsteady overland-flow soil erosion model is presented. This model simulates water and sediment outflow hydrographs. Considering the physical processes of interception, infiltration, and soil detachment by raindrop splash and by surface runoff. Sediment is routed by sizes and the concept of armoring is incorporated into the model. The effect of vegetation or other erosion control measures such as mulching is considered. The routing of water and sediment is accomplished by using a four-point implicit formulation of the kinematic approximation.

II. WATER BALANCE

Part of the rainfall is intercepted and stored by canopy and ground cover. Another portion is lost due to infiltration. These two amounts when deleted from the rainfall amount give the rainfall excess (i_e) which is then input into the water and sediment routing model.

INTERCEPTION LOSSES

The amount of interception losses depends on the percentage of the ground that is covered by canopy and ground cover as well as their respective water holding capacities. The total intercepted volume can be written as:

$$V_i = C_c V_c + C_g V_g \tag{2-1}$$

in which V_i is the total intercepted volume in depth, C_c is the canopy cover density ($0 \leq C_c \leq 1$), V_c is the potential volume of canopy cover interception in depth, C_g is the ground cover density ($0 \leq C_g \leq 1$) and, V_g is the potential volume of ground cover interception in depth.

As the computations proceed through time, the rainfall is all intercepted until the potential volumes for ground and canopy cover are filled. Although interception losses are continuous over the storm period it is assumed that the losses occur only in the beginning period of the storm.

INFILTRATION LOSSES

The infiltration losses are calculated using a solution of the Green-Ampt method first proposed in 1911. The method is applied under three assumptions.

1. A distinct piston wetting front exists.
2. The hysteresis effects in the soil properties are negligible.
3. The pressure effect of ponded water is negligible.

The third assumption is not necessary for the derivation of the original Green-Ampt equation but it is used in the following development. A Green-Ampt type equation may be written as

$$\frac{F}{\alpha'} - \ell n\left(1 + \frac{F}{\alpha'}\right) = \frac{Kt}{\alpha'} \tag{2-2}$$

in which F is the infiltrated volume, K is the hydraulic conductivity of the soil, t is time and α' is defined as

$$\alpha' = \phi(S_w - S_i)\psi_{ave} \tag{2-3}$$

in which ϕ is the porosity of the soil, S_w is the degree of saturation of the soil after wetting, S_i is the initial degree of saturation and, ψ_{ave} is the average suction head across the wetting front.

If at any time t the infiltrated volume is $F(t)$, then at some later time $t + \Delta t$

$$F(t + \Delta t) = F(t) + \Delta F \tag{2-4}$$

in which ΔF is the change in infiltrated volume which occurred during the time increment Δt. An expression for ΔF is obtained from Eq. (2-4)

$$\Delta F = F(t + \Delta t) - F(t) \tag{2-5}$$

Eggert (1976) developed the following method of solving for the infiltration rate. His derivation yields

$$\frac{\Delta F}{\alpha'} - \ell n\left[\frac{\alpha'+F(t)+\Delta F}{\alpha'+F(t)}\right] = \frac{K}{\alpha'}\ \Delta t \tag{2-6}$$

Equation (2-6) is implicit with respect to ΔF. However, the equation is simplified by expanding the logarithmic term in a power series (see Li et al., 1976).

$$\ell n\left(1 + \frac{\Delta F}{\alpha'+F}\right) = \ell n 1 + \frac{\frac{2\Delta F}{\alpha'+F}}{2 + \frac{\Delta F}{\alpha'+F}} + \ldots \tag{2-7}$$

Truncating Eq. (2-7) after the second term and substituting into Eq. (2-6) Eggert shows that

$$\frac{\Delta F}{\alpha'} - 2\left[\frac{\frac{\Delta F}{\alpha'+F}}{2 + \frac{\Delta F}{\alpha'+F}}\right] = \frac{K}{\alpha'}\,\Delta t \tag{2-8}$$

Equation 2-8 is simplified into a quadratic whose solution is (see Eggert, 1976)

$$\Delta F = -\frac{(2F - K\Delta t)}{2} + \frac{\left[(2F-K\Delta t)^2 + 8K\Delta t(\alpha'+F)\right]^{\frac{1}{2}}}{2} \tag{2-9}$$

Only the positive root of Eq. (2-9) has any physical significance. The average infiltration rate, $\bar{f}$, is obtained by dividing ΔF by Δt, or

$$\bar{f} = \frac{\Delta F}{\Delta t} \tag{2-10}$$

After accounting for the interception and infiltration losses the rainfall excess, i_e, can be determined. A rainfall event is commonly reported as a hyetograph, i.e., a series of rainfall intensities, I, each lasting for a time increment, Δt. Thus, if the rainfall intensity is greater than the infiltration rate; the infiltration rate is subtracted from the rainfall intensity to give the excess rainfall. If the rainfall intensity is less than the corresponding infiltration rate, the infiltration rate equals the rainfall intensity, and there is no excess.

III. SECOND ORDER NONLINEAR KINEMATIC WAVE APPROXIMATION FOR WATER ROUTING USING FOUR-POINT IMPLICIT FORMULATION

In this section a second-order, nonlinear kinematic wave model for water routing using four points will be developed. The model is developed for several reasons as given by Li et al. (1975a).

1. A linearized numerical scheme is sometimes unstable especially when supercritical flow is encountered.
2. Many numerical schemes require a downstream boundary condition which is not usually available.
3. Many numerical schemes are too complicated to apply for large scale modeling.

In addition to these reasons a simple numerical model is applicable in many cases when no analytical solutions exist. Only problems with specific boundary conditions and under spatially uniform and unsteady lateral inflow could be solved. Li et al. (1975b), Kibler and Woolhiser (1970), Harley et al. (1970) present various versions of analytical solutions to the kinematic wave approximation for unsteady overland flow water routing. However analytic solutions are further restricted by the formation of kinematic shock. Kinematic shock results when characteristic paths intersect. Physically this may be described as a faster moving parcel of water overtaking a slower moving parcel of water as they both travel downstream. Analytic solutions for problems which have kinematic shock display discontinuities in their hydrographs (see Kibler and Woolhiser, 1970). Under these restrictions and for the above reasons a simple numerical method is often desirable.

GOVERNING EQUATIONS

Runoff is described by the equation of continuity, the equation of motion, and equations describing flow resistance. These equations used in the nonlinear, four-point routing scheme are described below

Continuity Equation

The continuity equation for water can be expressed as,

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = i_e \qquad (3\text{-}1)$$

where q is the discharge per unit width, x is the downslope distance, y is the depth of flow, t is the time, and i_e is the excess rainfall amount.

Momentum Equation

Under the kinematic wave assumption the local and convective accelerations are assumed to be negligible and the water surface slope is also assumed to be equal to bed slope.

When using the Darcy-Weisbach friction factor, the momentum equation can be written as

$$S_o \simeq S_f = \frac{f' q^2}{8g\, y^3} \qquad (3\text{-}2)$$

where f' is the overall Darcy-Weisbach friction factor including form and grain resistance and g is the gravitational acceleration.

The Darcy-Weisbach friction factor f' depends on the roughness of the boundary, the depth of flow, rainfall intensity and the flow Reynolds number. By definition the flow Reynolds number N_r is

$$N_r = q/\nu \qquad (3\text{-}3)$$

in which ν is the kinematic viscosity of the fluid.

The relation between friction factor and Reynolds number is presented in fluid mechanics textbooks (e.g., Daily and Harlman, 1966, p. 274). The Darcy-Weisbach friction factor is only expressed in equation form for certain ranges of Reynolds number.

The effect of rainfall on flow resistance is a major factor in shallow water routing. For shallow flows the impact of raindrops causes energy losses in addition to those caused by boundary resistance. Shen and Li (1973) have experimentally determined equations for the Darcy-Weisbach friction factor for flow with raindrop impact and smooth boundary. Their equations have the general form,

$$f' = \frac{a_2}{N_r^{b_2}} \tag{3-4}$$

in which a_2 and b_2 are functions of rainfall intensity, boundary roughness, and the flow Reynolds number.

For $N_r < 900$

$$f' = \frac{K_1}{N_r} = \frac{K_o + K_r I^{0.41}}{N_r} \tag{3-5}$$

in which K_1 is a parameter which varies with rainfall intensity, K_o is a constant representing the grain resistance in the Darcy-Weisbach friction factor without rainfall, I is the rainfall intensity in inches per hour, and K_r is a number dependent on the raindrop velocity. Shen and Li (1973) have determined that K_r equals 27 for a raindrop fall of 8 ft.

For $N_r > 2000$, Shen and Li (1973) found that the friction factor was not affected by rainfall. The friction factor then may be approximated by the Blasius form of the resistance equation, which is,

$$f' = \frac{K_2}{N_r^{0.25}} \tag{3-6}$$

in which K_2 is a constant.

Recently Chen (1976) reported that for grass and turf surfaces the form of equation (3-5) is valid up to Reynolds number on the order of 10^5. This would practically cover all of the possible overland flow conditions. However, the value of K_1 is substantially larger than that of a smooth boundary.

In this study the overall flow resistance is assumed as

$$K_1 = K_\ell + (K_h - K_\ell)\, C_g^{\,2} \tag{3-7}$$

in which K_ℓ is the parameter describing the minimum resistance, K_h is the parameter describing the maximum resistance and C_g is the ground cover density.

Discharge and Flow Area Relation

The flow cross-sectional area can be expressed as a power function of discharge,

$$y = \alpha\, q^{\beta} \tag{3-8}$$

in which α and β are coefficients whose values depend on channel shape, roughness and slope.

If the Darcy-Weisbach Friction Factor is used, α and β may be determined from Equations (3-2), (3-3) and (3-4).

$$\alpha = \left[\frac{a_2 \nu^{b_2}}{8\, g\, S_o}\right]^{1/3} \tag{3-9}$$

$$\beta = (2-b_2)/3 \tag{3-10}$$

NUMERICAL SCHEME

A nonlinear scheme with an iterative procedure is developed to solve a four-point implicit formulation of Eqs. 3-1 and 3-8. A linear scheme is used to obtain the initial estimate of the unknown discharge for the nonlinear scheme. The linear scheme may be used as is, with no iterations to solve for the unknown discharge if the accuracy is satisfied.

Nonlinear Scheme

The finite difference form of Eq. 3-1 using quantities at all four points (see Fig. 3-1) of the box scheme can be written as

$$\left[\frac{q_{j+1}^{n+1} - q_j^{n+1}}{\Delta x}(1-a) + \frac{q_{j+1}^{n} - q_j^{n}}{\Delta x}(a)\right] + \left[\frac{y_{j+1}^{n+1} - y_{j+1}^{n}}{\Delta t}(1-b) + \frac{y_j^{n+1} - y_j^{n}}{\Delta t}(b)\right] = \frac{i_{ej+1}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n+1} + i_{ej}^{n}}{4} \qquad (3\text{-}11)$$

in which q_j^n is the quantity q at grid point $x = j\Delta x$, $t = n\Delta t$, where Δx is the space increment and Δt is the time increment. Also, a is the space weighting factor and b is the time weighting factor where $0 \leq a \leq 1$ and $0 \leq b \leq 1$.

The unknowns in Eq. 3-11 are q_{j+1}^{n+1}, and y_{j+1}^{n+1} but they are related according to Eq. 3-8. With the two equations the two unknowns may be calculated. The boundary conditions required for this particular formulation are as follows: $q(0,t)$ and $q(x,0)$ or in other words, the discharge must be known or assumed along both the space axis $[q(x,0)]$ and the time axis $[q(0,t)]$. No downstream boundary conditions are required. However, if there is a strong downstream control, the kinematic wave approximation no longer applies.

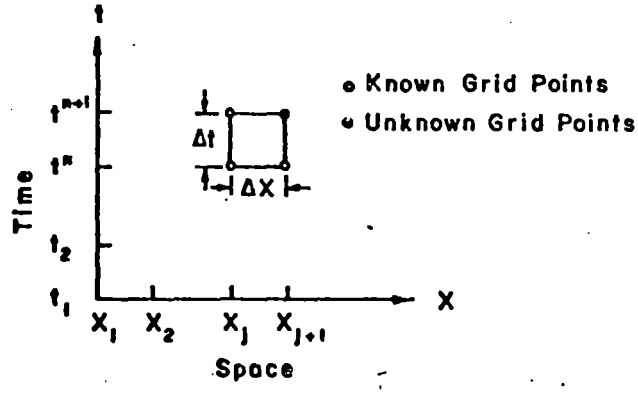

Figure 3-1. Rectangular Grid in Space-Time Plane

Either q or y may be selected as the independent variable in the numerical procedure. As customary in backwater computations the depth of flow is chosen as the independent variable (see Henderson, 1966), but Li, et al. (1975a) shows that q is a better choice.

From Eq. 3-8,

$$y_{j+1}^{n+1} = \alpha \, (q_{j+1}^{n+1})^{\beta} \tag{3-12}$$

$$y_{j}^{n+1} = \alpha \, (q_{j}^{n+1})^{\beta} \tag{3-13}$$

$$y_{j+1}^{n} = \alpha \, (q_{j+1}^{n})^{\beta} \tag{3-14}$$

$$y_{j}^{n} = \alpha \, (q_{j}^{n})^{\beta} \tag{3-15}$$

Equations 3-12 through 3-15 are substituted into Eq. 3-11 and rearranged to yield,

$$\begin{aligned} \frac{\Delta t}{\Delta x} q_{j+1}^{n+1} \, (1\text{-}a) + \alpha \, (q_{j+1}^{n+1})^{\beta} \, (1\text{-}b) = {} & \frac{\Delta t}{\Delta x} \{q_{j}^{n+1} \, (1\text{-}a) - [q_{j+1}^{n} - q_{j}^{n}] \, (a)\} \\ & + \alpha \, (q_{j+1}^{n})^{\beta} \, (1\text{-}b) - [\alpha \, (q_{j}^{n+1})^{\beta} - \alpha \, (q_{j}^{n})^{\beta}] \, (b) \\ & + \frac{\Delta t}{4} \{i_{ej+1}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n+1} + i_{ej}^{n}\} \end{aligned} \tag{3-16}$$

The right-hand side of Eq. 3-16 consists of known quantities and is represented by Ω.

$$\begin{aligned} \Omega = {} & \frac{\Delta t}{\Delta x} \{q_{j}^{n+1} \, (1\text{-}a) - [q_{j+1}^{n} - q_{j}^{n}] \, (a)\} + \alpha \, (q_{j+1}^{n})^{\beta} \, (1\text{-}b) \\ & - [\alpha \, (q_{j}^{n+1})^{\beta} - \alpha \, (q_{j}^{n})^{\beta}] \, (b) + \frac{\Delta t}{4} \{i_{ej+1}^{n+1} + i_{ej}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n}\} \end{aligned} \tag{3-17}$$

Let $r = q_{j+1}^{n+1}$ and $\theta = \frac{\Delta t}{\Delta x}$ so that the left-hand side of Eq. 3-16 can be written as

$$f(r) = \theta \, (1\text{-}a) r + \alpha \, (1\text{-}b) r^{\beta} \tag{3-18}$$

The solution to Eq. 3-16 is the solution r^* which satisfies the condition,

$$f(r^*) = \theta(1-a)r^* + \alpha(1-b)r^{*\beta} = \Omega \tag{3-19}$$

Equation 3-19 is nonlinear in r^*. An approximate solution to this nonlinear equation is obtained by the following iterative technique.

Let r^k be the value of r at the kth iteration. The Taylor series expansion of the function $f(r)$ around r^k is

$$f(r) = f(r^k) + (r-r^k)\, f'(r^k) + 1/2(r-r^k)^2\, f''(r^k) + 1/6(r-r^k)^3\, f'''(r^k) \tag{3-20}$$

in which $f'(r^k)$, $f''(r^k)$, and $f'''(r^k)$ are the first, second and third derivatives of the function at r^k.

Dropping terms higher than second order one obtains,

$$f(r) \approx f(r^k) + (r-r^k)f'(r^k) + 1/2(r-r^k)^2\, f''(r^k) \tag{3-21}$$

Iteration forces $f(r^{k+1})$ to approach the value of Ω

$$\Omega = f(r^k) + (r^{k+1}-r^k)\, f'(r^k) + 1/2(r^{k+1}-r^k)^2\, f''(r^k) \tag{3-22}$$

The solution of Eq. 3-22 is

$$r^{k+1} = r^k - \frac{f'(r^k)}{f''(r^k)} \pm \left(\left(\frac{f'(r^k)}{f''(r^k)} \right)^2 - \frac{2[f(r^k)-\Omega]}{f''(r^k)} \right)^{1/2} \tag{3-23}$$

in which

$$f(r^k) = \theta(1-a)r^k + \alpha(1-b)(r^k)^\beta \tag{3-24}$$

$$f'(r^k) = \theta(1-a) + \alpha\beta(1-b)(r^k)^{\beta-1} \tag{3-25}$$

$$f''(r^k) = \alpha\beta(\beta-1)(1-b)(r^k)^{\beta-2} \tag{3-26}$$

There are two solutions to Eq. 3-23. It is advisable to choose the solution which gives the smaller value of $|f(r^{k+1})-\Omega|$. The iterations are continued until the absolute error $|f(r^{k+1})-\Omega|$ is less than some preassigned tolerance ϵ

$$|f(r^{k+1})-\Omega| \leq \epsilon \tag{3-27}$$

An appropriate value for ϵ is 0.01 Ω.

The initial guess r° is the key to the speed of convergence to the correct numerical solution. The best way to determine r° is to use a linear scheme. The linear scheme may be used as the solution instead of going through the iterative, nonlinear scheme when accuracy is of less importance and when computer time is to be conserved.

Linear Scheme

The term $\frac{\partial y}{\partial t}$ in Eq. 3-1 can be expressed as,

$$\frac{\partial y}{\partial t} = \frac{\partial y}{\partial q}\frac{\partial q}{\partial t} \tag{3-28}$$

and from Eq. 3-8

$$\frac{\partial y}{\partial q} = \alpha\beta q^{\beta-1} \tag{3-29}$$

Substitution of Eqs. 3-28 and 3-29 into 3-1 yields

$$\frac{\partial q}{\partial x} + \alpha\beta q^{\beta-1}\frac{\partial q}{\partial t} = i_e \tag{3-30}$$

The finite difference form of 3-30 can be expressed as

$$\frac{q_{j+1}^{n+1} - q_j^{n+1}}{\Delta x}(1-a) + \frac{q_{j+1}^{n} - q_j^{n}}{\Delta x}(a)$$

$$+ \alpha\beta \left[\frac{q_j^{n+1} + q_{j+1}^{n}}{2}\right]^{\beta-1} \left[\frac{q_{j+1}^{n+1} - q_{j+1}^{n}}{\Delta t}(1-b) + \frac{q_j^{n+1} - q_j^{n}}{\Delta t}(b)\right]$$

$$= 1/4\ [i_{ej+1}^{n+1} + i_{ej}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n}] \qquad (3\text{-}31)$$

Solving for $r^\circ = q_{j+1}^{n+1}$,

$$q_{j+1}^{n+1} = \left[\frac{1-a}{\Delta x} + \alpha\beta\left(\frac{q_j^{n+1} + q_{j+1}^{n}}{2}\right)^{\beta-1} \frac{(1-b)}{\Delta t}\right]^{-1} \left\{\frac{q_j^{n+1}}{\Delta x}(1-a) - \frac{q_{j+1}^{n} - q_j^{n}}{\Delta x}(a)\right.$$

$$- \alpha\beta\left(\frac{q_j^{n+1} + q_{j+1}^{n}}{2}\right)^{\beta-1} \left[-\frac{q_{j+1}^{n}}{\Delta t}(1-b) + \frac{q_j^{n+1} - q_j^{n}}{\Delta t}(b)\right]$$

$$\left. + 1/4\ [i_{ej+1}^{n+1} + i_{ej}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n}]\right\} \qquad (3\text{-}32)$$

Equation 3-32 provides the best estimate r° for the nonlinear scheme. However, Eq. 3-32 is not applicable if both q_{j+1}^{n} and q_j^{n+1} are zero. In this case, use $\beta=1$ in Eq. 3-18

$$r^\circ = \Omega/((1-a)\theta + (1-b)\alpha) \qquad (3\text{-}33)$$

Stability

Suppose $\eta(x,t)$ and $\xi(x,t)$ are the values of the error in $q(x,t)$ and $y(x,t)$ which occur in the numerical computations. Then,

$$\eta(x,t) = q^*(x,t) - q(x,t) \qquad (3\text{-}34)$$

$$\xi(x,t) = y^*(x,t) - y(x,t) \qquad (3\text{-}35)$$

in which q^* and y^* represent the true values of discharge and area.

Using the relationship (Eq. 3-8),

$$y^*(x,t) = \alpha\ [q^*(x,t)]^\beta \qquad (3\text{-}36)$$

If q and y are in error by the values of the error functions $\eta(x,t)$ and $\xi(x,t)$ then,

$$y^*(x,t) - \xi(x,t) = \alpha\,[q^*(x,t) - \eta(x,t)]^{\beta}$$

$$= \alpha\,[q^*(x,t)]^{\beta}\left[1 - \frac{\eta(x,t)}{q^*(x,t)}\right]^{\beta} \qquad (3\text{-}37)$$

assuming that $\frac{\eta(x,t)}{q^*(x,t)} << 1$, the power series expansion of $\{1 - [\eta(x,t)/q^*(x,t)]\}^{\beta}$ is approximately $1-\beta[\eta(x,t)/q^*(x,t)]$. Substitution of this result into Eq. 3-37 yields the expression

$$y^*(x,t) - \xi(x,t) = \alpha\,[q^*(x,t)]^{\beta} - \alpha\beta\,[q^*(x,t)]^{\beta-1}\,\eta(x,t) \qquad (3\text{-}38)$$

When Eq. 3-38 is subtracted from Eq. 3-36 the result is,

$$\xi(x,t) = \alpha\beta\,[q^*(x,t)]^{\beta-1}\,\eta(x,t) = \delta\eta(x,t) \qquad (3\text{-}39)$$

in which δ is the error-free factor $\alpha\beta\,[q^*(x,t)]^{\beta-1}$. At a given time in the calculations q_j^n and y_j^n may be in error by the value of the error functions η_j^n and ξ_j^n, and q_{j+1}^n and y_{j+1}^n may be in error by the amounts η_{j+1}^n and ξ_{j+1}^n; etc.

When written for this case, Eq. 3-19 becomes

$$\left[\frac{(q_{j+1}^{n+1} + \eta_{j+1}^{n+1}) - (q_j^{n+1} + \eta_j^{n+1})}{\Delta x}(1\text{-a}) + \frac{(q_{j+1}^{n} + \eta_{j+1}^{n}) - (q_j^{n} + \eta_j^{n})}{\Delta x}(\text{a})\right]$$

$$+\left[\frac{(y_{j+1}^{n+1} + \xi_{j+1}^{n+1}) - (y_{j+1}^{n} + \xi_{j+1}^{n})}{\Delta t}(1\text{-b}) + \frac{(y_{j}^{n+1} + \xi_{j}^{n+1}) - (y_{j}^{n} + \xi_{j}^{n})}{\Delta t}(\text{b})\right]$$

$$= 1/4\,[i_{ej+1}^{n+1} + i_{ej+1}^{n} + i_{ej}^{n+1} + i_{ej}^{n}] \qquad (3\text{-}40)$$

When Eq. 3-11 is subtracted from Eq. 3-40 the result is

$$\theta[(\eta_{j+1}^{n+1} - \eta_j^{n+1})\ (1-a) + (\eta_{j+1}^{n} - \eta_j^{n})\ (a)] + [(\xi_{j+1}^{n+1} - \xi_{j+1}^{n})\ (1-b) + (\xi_j^{n+1} - \xi_j^{n})\ (b)] = 0 \qquad (3\text{-}41)$$

Substituting Eq. 3-39 into Eq. 3-41 yields

$$\theta[(\eta_{j+1}^{n+1} - \eta_j^{n+1})\ (1-a) + (\eta_{j+1}^{n} - \eta_j^{n})\ (a)] + \delta[(\eta_{j+1}^{n+1} - \eta_{j+1}^{n})\ (1-b) + (\eta_j^{n+1} - \eta_j^{n})(b)] = 0 \qquad (3\text{-}42)$$

When the function $\eta(x,t)$ is decomposed x-wise into the Fourier series, it takes the form

$$\eta(x,t) = \sum_m a(m,t)\ e^{i2\pi mx/L} \qquad (3\text{-}43)$$

in which $a(m,t)$ is the error component amplitude, L is the length of reach being computed, and $i = (-1)^{1/2}$. Substitution of Eq. 3-43 into Eq. 3-42 and examination of each Fourier component separately shows that

$$\theta(1-a)\ [\sum_m A(m,t_{n+1})\ e^{i2\pi m(x_j+\Delta x)/L} - \sum_m A(m,t_{n+1})\ e^{i2\pi mx_j/L}]$$
$$+ \theta(a)\ [\sum_m A(m,t_n)\ e^{i2\pi m(x_j+\Delta x)/L} - \sum_m A(m,t_n)\ e^{i2\pi mx_j/L}]$$
$$+ \delta(1-b)\ [\sum_m A(m,t_{n+1})\ e^{i2\pi m(x_j+\Delta x)/L} - \sum_m A(m,t_n)\ e^{i2\pi m(x_j+\Delta x)/L}]$$
$$+ \delta(b)\ [\sum_m A(m,t_{n+1})\ e^{i2\pi mx_j/L} - \sum_m A(m,t_n)\ e^{i2\pi mx_j/L}] = 0 \qquad (3\text{-}44)$$

Division by $\exp(i2\pi mx_j/L)$, denoting $\psi = 2\pi m\Delta x/L$ and rearranging, Eq. 3-44 reduces to

$$\sum A(m,t_{n+1})\ \{\theta(1-a)\ [e^{i\psi}-1] + \delta\ (1-b)\ e^{i\psi} + \delta(b)\}$$
$$+ \sum A(m,t_n)\ \{\theta(a)\ [e^{i\psi}-1] - \delta(1-b)\ e^{i\psi} - \delta(b)\} = 0 \qquad (3\text{-}45)$$

Then

$$\left|\frac{A(m,t_{n+1})}{A(m,t_n)}\right| = \left|\frac{-\{\theta a[e^{i\psi}-1] - \delta(1-b)e^{i\psi}-\delta(b)\}}{\theta(1-a)[e^{i\psi}-1] + \delta(1-b)e^{i\psi}+\delta(b)}\right| \leq 1 \qquad (3\text{-}46)$$

In other words, the amplitude of the error must decrease with each succeeding time increment in order to be stable.

Expanding $e^{i\psi}$ into its components $\cos\psi + i\sin\psi$ and finding the magnitude of both numerator and denominator of Eq. 3-46 gives the following result,

$$\theta(2a-1) + \delta(2b-1) \leq 0 \qquad (3\text{-}47)$$

or,

$$a \leq 1/2,\ b \leq 1/2 \qquad (3\text{-}48)$$

Therefore a and b must be less than or equal to 1/2 to insure stability.

Before testing convergence of the model by comparing the numerical results with analytical solutions to a hypothetical problem, one other constraint on the weight factors a and b is discussed.

By taking the partial derivative of Eq. 3-17 with respect to q_j^{n+1} and assuming $a = b$ and the lateral inflow is zero, the following expression results,

$$\frac{\partial \Omega}{\partial q_j^{n+1}} = \theta(1-a) - a\beta\alpha(q_j^{n+1})^{\beta-1} \geq 0 \qquad (3\text{-}49)$$

This expression must be greater than or equal to zero so that when q_j^{n+1}, the upstream discharge at time increment $n+1$, increases, Ω also increases. Therefore, solving for a,

$$a \leq \frac{\theta}{\theta+\alpha\beta(q_j^{n+1})^{\beta-1}} \qquad (3\text{-}50)$$

When a and b are both zero, this is a fully-implicit scheme. When a and b equal 1/2, it is a central-implicit scheme.

IV. SEDIMENT ROUTING

An important problem in land use and water resource planning is the prediction of soil erosion from the land surface. Water and sediment routing models such as the one developed by Simons et al. (1975) provide a method of estimating time dependent responses for water and sediment from watersheds. Herein, a water and sediment routing model for predicting soil erosion from the land surface is now formulated based on the same approach given by Simons et al. (1975). Some modifications are made to improve the accuracy and utility of the model. The water-routing portion of the model is the four-point implicit scheme under the kinematic wave assumption given in Chapter III. The sediment-routing portion of the model is similar to the formulation used by Simons et al. (1975), but extended to the four-point implicit scheme and considers the routing of different sediment sizes. The attention of routing sediment by sizes is increasing because different sizes of sediment have different uptake rates for water pollutants or nutrients.

GOVERNING EQUATIONS

The movement of sediment from a watershed is governed by the equation of continuity for sediment and sediment transport equations. The amount of soil that could be transported is described by equations of sediment supply. These include soil detachment by raindrop impact and soil detachment by surface runoff. The equations used in the model are described below.

Continuity for Sediment

The equation of continuity for sediment can be expressed as (see Simons et al., 1975):

$$\frac{\partial q_s}{\partial x} + \frac{\partial Cy}{\partial t} + \frac{\partial z}{\partial t} = 0 \qquad (4\text{-}1)$$

in which

$$C = \frac{q_s}{q} \qquad (4\text{-}2)$$

and q_s is the total sediment transport rate by volume, C is the sediment concentration by volume, z is the net depth of loose soil.

The sediment load can be broken into two main categories; bed material load and wash load. But in order to simulate the actual grain size distribution found in soil samples, the sediment load will be broken into any specified numbers of size fractions. The sediment continuity equation is then written using arrayed variables according to sediment size. The percentage of sediment in each size fraction is accounted for in the transport equations.

$$\frac{\partial q_{si}}{\partial x} + \frac{\partial C_i y}{\partial t} + \frac{\partial z_i}{\partial t} = 0 \qquad (4\text{-}3)$$

in which i indicated which size fraction is being calculated (i=1, number of size fractions).

Sediment Transport Equations

The sediment transport equations are used to determine the sediment transporting capacity of a specific flow condition. Different transporting capacities are expected for different sediment sizes. The transporting rate for each sediment size can be divided into the bed load transport rate and the suspended-load transport rate. The following

equations are used in this study to determine the transporting capacity of the flow for each size fraction.

A simple and widely used bed-load transport equation is the Meyer-Peter, Muller equation (see USBR, 1960).

$$q_b = \frac{12.85}{\sqrt{\rho}\,\gamma_s}(\tau_o - \tau_c)^{1.5} \tag{4-4}$$

in which

$$\tau_c = \delta_s(\gamma_s - \gamma)d_s \tag{4-5}$$

where q_b is the bed-load transport rate in volume per unit width, τ_o is the boundary shear stress acting on the grain, τ_c is the critical tractive force, γ_s is the specific weight of water, ρ is the density of water ($\rho = \frac{\gamma}{g}$), d_s is the sediment size and δ_s is a constant.

The flow discharge q and depth y are determined in space and time by the water routing procedure described in Chapter III. Knowing these values the corresponding value of τ_o can be computed as follows.

$$V = q/y \tag{4-6}$$

The boundary shear stress acting on the grain is then,

$$\tau_o = \frac{1}{8}\rho f V^2 \tag{4-7}$$

in which f is the Darcy-Weisbach friction factor due to grain resistance. Note that the velocity is calculated using f' in the water-routing procedure where f' is the overall resistance factor.

The sediment concentration profile which relates the sediment concentration with distance above the bed (see Simons et al. 1975) can be written as

$$\frac{C_\xi}{C_{a^*}} = \left(\frac{y-\xi}{\xi}\,\frac{a^*}{y-a^*}\right)^w \tag{4-8}$$

in which C_ξ is the sediment concentration at a distance ξ from the bed, C_{a^*} is the known concentration at a distance "a*"above the bed, y is again the depth of flow, and w is a parameter defined as:

$$w = \frac{V_s}{0.4U_*} \tag{4-9}$$

Here V_s is the settling velocity of the sediment particles and U_* is the shear velocity defined as:

$$U_* = \left(\frac{\tau_*}{\rho}\right)^{1/2} \tag{4-10}$$

in which τ_* is defined as

$$\tau_* = \frac{1}{8} f'\rho V^2 \tag{4-11}$$

A logarithmic velocity profile is commonly adopted to describe the velocity distribution of turbulent flow and can be written:

$$\frac{U_\xi}{U_*} = B_1 + 2.5\ \ell n\ \left(\frac{\xi}{\eta_s}\right) \tag{4-12}$$

in which U_ξ is the point mean velocity at a distance ξ above the bed, B_1 is a constant dependent on roughness, and η_s is the roughness height.

The integral of suspended load above"a*" level in the flow is obtained by combining Eqs. 4-8 and 4-12.

$$q_s = \int_a^y U_\xi C_\xi d_\xi$$

$$= C_{a^*} U_* \int_{a^*}^{y} \left[B_1 + 2.5\ \ell_n\ \left(\frac{\xi}{\eta_s}\right)\right]\ \left(\frac{y-\xi}{\xi}\,\frac{a^*}{y-a^*}\right)^w d\xi \tag{4-13}$$

Let

$$\sigma = \frac{\xi}{y}$$

and

$$G = \frac{a^*}{y}$$

Substitution into Eq. 4-13 yields:

$$q_{s\ell} = C_{a^*} U_* a^* \frac{G^{w-1}}{(1-G)^w} \{[B_1 + 2.5\ \ell n\ (\frac{y}{\eta_s})] \int_G^1 (\frac{1-\sigma}{\sigma})^w\ d\sigma + 2.5 \int_G^1 \ell n\sigma (\frac{1-\sigma}{\sigma})^w\ d\sigma\} \quad (4\text{-}14)$$

According to Einstein (1950), the sediment concentration near the bed layer C_{a^*} is related to the bed-load transport rate q_b

$$q_b = 11.6\ C_{a^*} U_* a^* \quad (4\text{-}15)$$

in which a^* is redefined as the thickness of the bed layer which is twice the size of the sediment.

The average flow velocity V is defined by the equation:

$$V = \frac{\int_o^y U_\xi d\xi}{\int_o^y d\xi} \quad (4\text{-}16)$$

Using Eq. 4-12:

$$\frac{V}{U_*} = B_1 + 2.5\ \ell n\ (\frac{y}{\eta_s}) - 2.5 \quad (4\text{-}17)$$

Einstein (1950) defined the two integrals in Eq. 4-14 as:

$$J_1 = \int_G^1 \left(\frac{1-\sigma}{\sigma}\right)^w d\sigma \tag{4-18}$$

and

$$J_2 = \int_G^1 \left(\frac{1-\sigma}{\sigma}\right)^w \ell n\sigma d\sigma \tag{4-19}$$

The integrals J_1 and J_2 cannot be integrated in closed form for most values of w so a numerical method of determining J_1 and J_2 developed by Li (1974) is adopted in this study.

Substitution of Eqs. 4-15, 4-17, 4-18, and 4-19 into Eq. 4-14 yields the expression given by Simons et al. (1975).

$$q_{s\ell} = \frac{q_b}{11.6} \frac{G^{w-1}}{(1-G)^w} \left[\left(\frac{V}{U_*} + 2.5\right) J_1 + 2.5\, J_2\right] \tag{4-20}$$

The total sediment load per unit width is:

$$q_t = q_b + q_{s\ell} \tag{4-21}$$

and the sediment transporting capacity of the section q_c is

$$q_c = q_t \tag{4-22}$$

When considering transport by different sizes Eq. 4-22 should be modified as follows:

$$q_{ci} = F_{ai}\, q_{ti} \tag{4-23}$$

in which F_{ai} is the adjusted fraction of sediment in the ith size (see section entitled Soil Detachment by Raindrop Impact).

Equations for Sediment Supply

The sediment supply rate is another determining factor in the actual sediment transport rate. Simons et al. (1975) states that the sediment supply depends on the initial depth of loose soil left from previous storms, the amount of soil detachment by raindrop impact, and the amount of soil detachment by overland flow erosion.

Soil Detachment by Raindrop Impact. The potential rate of soil detachment by raindrop impact can be written as a power function of rainfall intensity as given by Meyer 1975.

$$D_r = a_3' \, i^{b_3'} \left(1 - \frac{Z_w}{Z_m}\right) \tag{4-24}$$

in which i is the rainfall intensity, a_3' is a parameter depending on soil characteristics and b_3' is a constant ($b_3' = 2.0$, see Meyer, 1975). The term Z_w is the depth of water plus the loose soil depth. The term Z_m is the maximum penetration depth of raindrop splash. According to Mutchler and Young (1975), Z_m is equal to three times the median raindrop size. The median raindrop size can be written as a power function of rainfall intensity. Therefore, Z_m can be written as:

$$Z_m = 3(2.23 \, i^{0.182}) \tag{4-25}$$

Equation 4-24 is valid when Z_w is less than Z_m. When the depth of loose soil plus the water depth is greater than Z_m, D_r is zero.

$$D_r = 0, \; Z_w > Z_m \tag{4-26}$$

The potential rate of loose soil detachment, D_r, is expressed in units of depth per unit time.

Thus the new amount of loose soil available for transport is:

$$Z_i = Z_i + F_i D_r \Delta t \tag{4-27}$$

where Z_i is respectively the amount of loose soil available and F_i is the original percentage of sediment size in a given size fraction designated by i.

The percentage in each size fraction on the surface changes over time due to armoring. The water transports the smaller sediment sizes more easily and leaves the larger size fractions behind. Thus, the percentages of surface material need adjustment each time step. If the total loose soil depth is greater than D_{84} (the size of sediment for which 84 percent of the sample is finer). The adjusted percentages, F_{ai}, can be written as:

$$F_{ai} = \frac{Z_i}{\sum_{i=1}^{M} Z_i} \tag{4-28}$$

If the total loose soil depth $\sum_{i=1}^{M} Z_i$ is less than D_{84} then the adjusted percentages must account for the layer of undisturbed soil which is distributed according to the original percentages plus the loose soil which covers it.

$$F_{ai} = \frac{1}{D_{84}} \left\{ Z_i + F_i \left[D_{84} - \sum_{i=1}^{M} Z_i \right] \right\} \tag{4-29}$$

Soil Detachment by Surface Runoff. The amount of soil detachment by surface runoff is determined by comparing the sediment transporting capacity to the total available amount of loose soil. By substituting

the sum of the transporting capacities, $\sum_{i=1}^{M} q_{ci}$ (given by summing the transport rates for M size fractions in Eq. 4-23), into the transporting rate given by Eq. 4-1 the total potential change in loose soil storage is determined.

$$\Delta Z^p = \frac{\partial Z^p}{\partial t} (\Delta t) \tag{4-30}$$

If $\Delta Z^p \geq - Z$, the loose soil storage is enough for transport and no detachment of soil by surface runoff is expected. Soil is detached if $\Delta Z^p < - Z$ and the amount of detachment is

$$D = - D_f(\Delta Z^p + Z) . \tag{4-31}$$

in which D is the total amount of detached soil and D_f is defined as a detachment coefficient with values ranging from 0.0 to 1.0 depending on soil erodibility. As an example, if the flow were over a nonerodible surface the value for D_f would be zero. If one were considering flow in a river where the riverbed is always loose the value for D_f would be unity.

The new amount of loose soil should be further modified as follows:

$$Z_i = Z_i + DF_i \tag{4-32}$$

in which Z_i is calculated for each size fraction of sediment.

Numerical Procedure for Sediment Routing

A numerical procedure for sediment routing used to couple the equations governing sediment motion with the water routing procedure is now presented.

The transporting capacity is determined by using Eq. 4-23 and the computed flow conditions from the water routing model. The potential

sediment load concentration for a given size fraction is then,

$$C_i^p = \frac{q_{ci}}{q_{j+1}^{n+1}} \tag{4-33}$$

These qualities are at time n+1 and space j+1 in the space-time plane (refer to Fig. 3-1). The same finite-difference scheme used in water routing is employed for sediment routing.

The potential change in loose soil storage for sediment in a given size fraction is:

$$\Delta Z_i^p = \{- \theta \, [(C_i^p q_{j+1}^{n+1} - q_{si\ j}^{\ n+1})\ (1\text{-}a)$$

$$+ (q_{si\ j+1}^{\ n} - q_{si\ j}^{\ n})a] - [(C_i^p\ y_{j+1}^{n+1} - C_{i\ j+1}^{\ n}\ y_{j+1}^{n})\ (1\text{-}b)$$

$$+ (C_{i\ j}^{\ n+1}\ y_j^{n+1} - C_{i\ j}^{\ n}\ y_j^{n})\ (b)]\} \tag{4-34}$$

if ΔZ_i^p is positive, that size of sediment is aggrading on the bed, and if negative that size of sediment is being transported off the bed.

The actual transport rate depends on both the availability of material and the transporting capacity of the flow. If $\Delta Z_i^p \geq - Z_i$, the availability is greater than the transporting capacity. Thus, the transport rate for material in size fraction I is equal to its transporting capacity or,

$$C_{i\ j+1}^{\ n+1} = C_i^p \tag{4-35}$$

and the actual change in Z_i is:

$$\Delta Z_i = Z_i^p \tag{4-36}$$

If $\Delta Z_i^p < - Z_i$, the availability of material is less than the transporting capacity. The transport rate is limited by the availability of loose soil and the bed material concentration is therefore,

$$C_{i\ j+1}^{n+1} = \{[(C_{i\ j+1}^{n}\ y_{j+1}^{n}\ (1-b) - (C_{i\ j}^{n+1}\ y_j^{n+1} - C_{i\ j}^{n}\ y_j^{n})\ (b)]$$

$$- \theta\ [-q_{si\ j}^{n+1}\ (1-a) + (q_{si\ j+1}^{n} - q_{si\ j}^{n})\ (a)] + Z_i\}/\{y_{j+1}^{n+1}\ (1-a)$$

$$+ \theta\ q_{j+1}^{n+1}\ (1-a)\} \qquad (4\text{-}37)$$

and

$$\Delta Z_i = - Z_i \qquad (4\text{-}38)$$

The sediment transport rate $q_{si\ j+1}^{n+1}$ is determined by Eq. 4-2,

$$q_{si\ j+1}^{n+1} = C_{i\ j+1}^{n+1}\ q_{j+1}^{n+1} \qquad (4\text{-}39)$$

and the amount of loose soil available at the next time increment is:

$$Z_i = Z_i + \Delta Z_i \qquad (4\text{-}40)$$

V. APPLICATION RESULTS

The water and sediment routing model is now validated using available measured data. The data were collected by Van Liew (1976) on mine spoil areas on Edna Mine in the Yampa Coal field of Routt County, Colorado. A portable rainfall simulator provided the necessary input on the mine spoil areas of known size and slope. The experiment conditions, calibration of the model and a comparison of the output to measured data follow.

EXPERIMENT CONDITIONS

The experimetal plots used by Van Liew were rectangular in shape and had various, selected slopes. Rainfall intensities studied were 1.44 and 2.26 inches per hour, or 36.5 and 57.4 mm/hr, respectively. Model results suggest that the supposed 1.44 in./hr rate was closer to 2.26 in./hr, therefore a rate of 2.26 in./hr was assumed for one case studied. Each plot consisted of bare soil composed of sandstone, siltstone and shale particles. Median grain size of the in place composite samples was 0.0175 mm (0.00069 inches). Water yields for each experiment were given by Van Liew and sediment yields were computed by integrating Van Liew's sediment hydrographs. The results of the integration were comparable to those calculated using Van Liew's average transport rates and similar to those shown by Van Liew (1976). The integrated values were used because the time span for the average transport rate determination was not precisely known and the values from figures given by Van Liew (1976) had to be scaled by hand and were not deemed as accurate. Although Van Liew (1976) conducted six rainfall simulation experiments, only two were utilized for calibrating the model. One of the other four cases was a multiple rainfall intensity event with the suspect 1.44

in./hr intensity as the primary input. The other cases were the first experiment in the series, one 7 percent slope, and two 1 percent slopes. These three cases were not used in sediment calibration runs, but were used as test cases using calibrated parameters. The original input data for the calibrations runs and three test runs is listed in Table 5.1.

TABLE 5.1 Experiment Plots Used

No.	i in./hr	Duration Minutes	Slope	Length, ft	Width, ft
1	2.26	50	0.07	31.29	12.69
2	2.26	46	0.07	31.29	12.69
3	2.26	51	0.01	32.31	12.31
4	2.26	63.9	0.01	32.31	12.31
5.	2.26	56.4	0.07	31.29	12.69

Note: Rainfall intensity adjusted from 1.44 to 2.26 in./hr for run No. 4.

Experimental runs number 1 and 2 were used as calibration runs and 3 through 5 were used as the test runs. Both ground and canopy cover for the sites were zero. The parameters describing overall resistance and grain resistance for the sites, K_1 and K_o, were assumed equal to 50, a commonly reported value for smooth bare soil (Woolhiser, 1975). The coefficient a for the raindrop splash detachment (Eq. 35) was assumed to be 0.0001 which is approximately what Van Liew (1976) reports in his results. The power on this same equation is set at 2.0. A composite grain size distribution for the on-site spoil material was extracted from information provided by Van Liew (personal communication). This grain size distribution was plotted then subdivided into 14 size classes as presented in Table 5.2. Note that size fraction percents

were taken at finer intervals for the larger sizes. This was done to enable better model simulation where a small change in size changes the overall sediment transport considerably.

TABLE 5.2. Sediment Size Distribution for Simulation

Geometric Mean (mm)	Percent of Sample
.00063	6.5
.00316	30.5
.0250	31.0
.0884	6.0
.1768	4.0
.3536	4.0
.6124	1.8
.8660	1.2
1.1180	1.0
1.3693	0.5
1.6202	0.5
2.0917	0.5
3.1623	3.5
8.000	9.0

CALIBRATION

The model was calibrated on the first two experiments so that the water and sidment yields agree clcsely. The correct water yield is achiedved by calibrating the hydraulic conductivity of the soil in the wetted zone, K, and the potential head parameter α', as shown in Eq. 2.2. The sediment yield and size distribution are contrclled by the

parameters δ_s and D_f (refer to equations 4-5 and 4-31 respectively). Calibration gives the following results:

1) K = 0.844 in./hr

2) α' = 0.13 in.

3) δ_s = 0.010

4) D_f = 0.00055

The above calibrations were acheived by applying the one-dimensional optimization technique (Simons and Li, 1976) with a method of projection (see Simons et al. 1977).

TABLE 5.3

Run No.	Actual Water Yield (ft^3)	Simulated Water Yield (ft^3)	Measured Sediment Yield (lbs)	Simulated Sediment Yield (lbs)
1	29.32	29.76	14.90	15.41
2	31.39	26.88	14.45	13.92
3	31.00	30.07	6.38	4.39
4	36.35	39.62	4.99	5.79
5	36.57	34.40	10.45	17.83

Figure 5.3 shows the above data compared to the line of perfect agreement. The simulated results agree reasonably well with the observed data.

The water and sediment hydrographs for run number 1 are plotted in figures 5.2 and 5.3. The results are acceptable.

Figure 5.4 gives the original sediment size distribution curve for the mine spoil plot. One can see that the size curves of the transported material is shifted to the left showing the armoring effect. The larger size fractions are not transported and thus the size distribution curve is expected to shift. The actual vs. simulated size distribution curves agree very well.

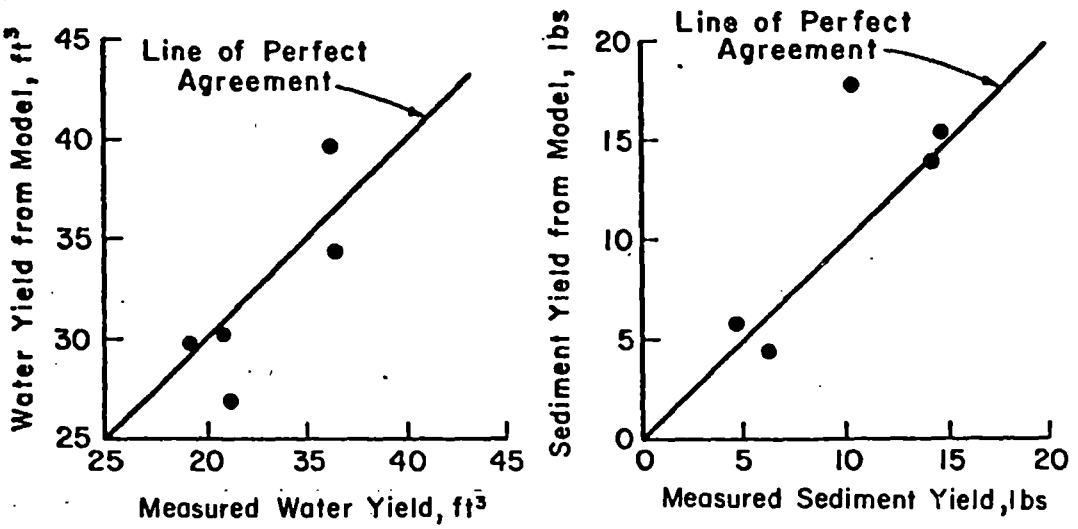

Figure 5.1. Comparison of Simulated and Observed Water and Sediment Yields

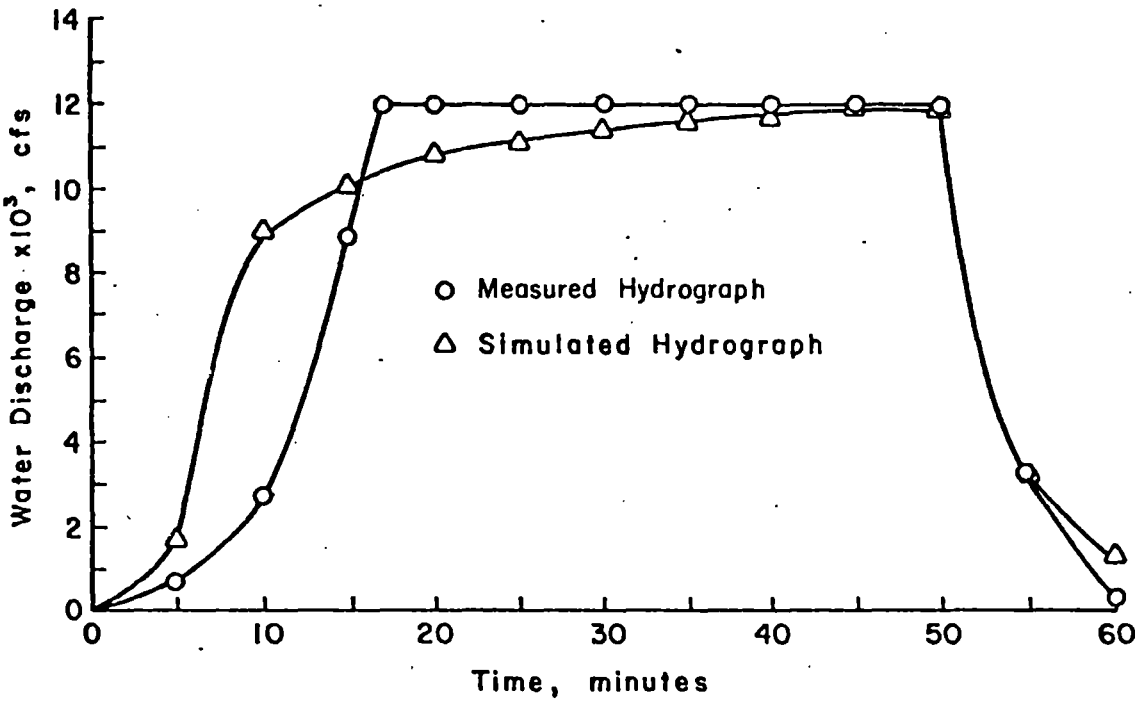

Figure 5.2. Comparison of Simulated and Observed Water Hydrograph for Run 1.

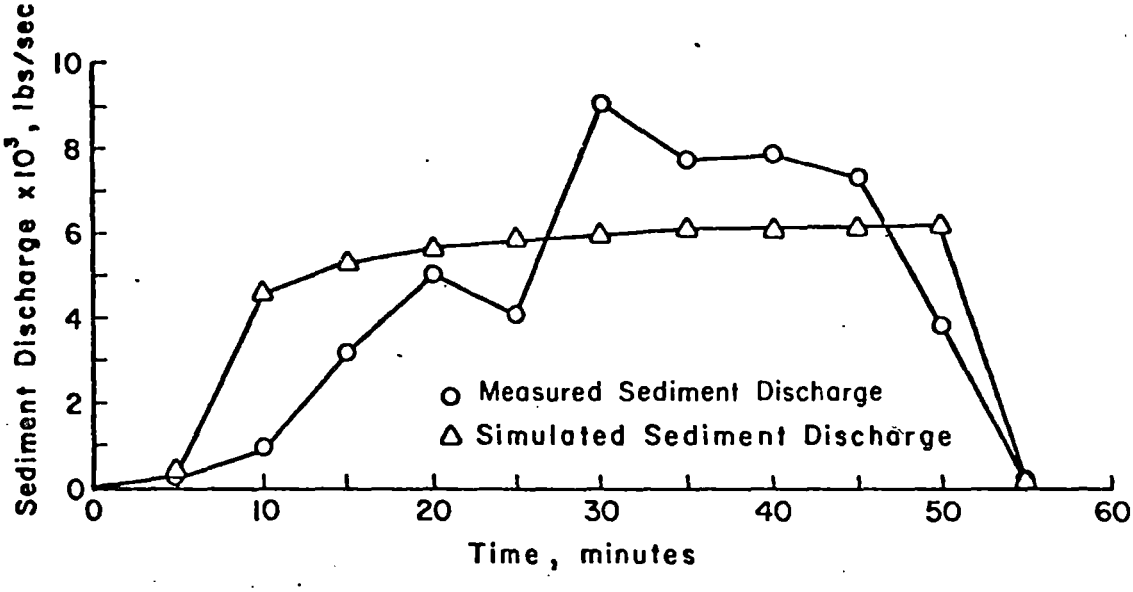

Figure 5.3. Comparison of Simulated and Observed Sediment Hydrograph for Run 1.

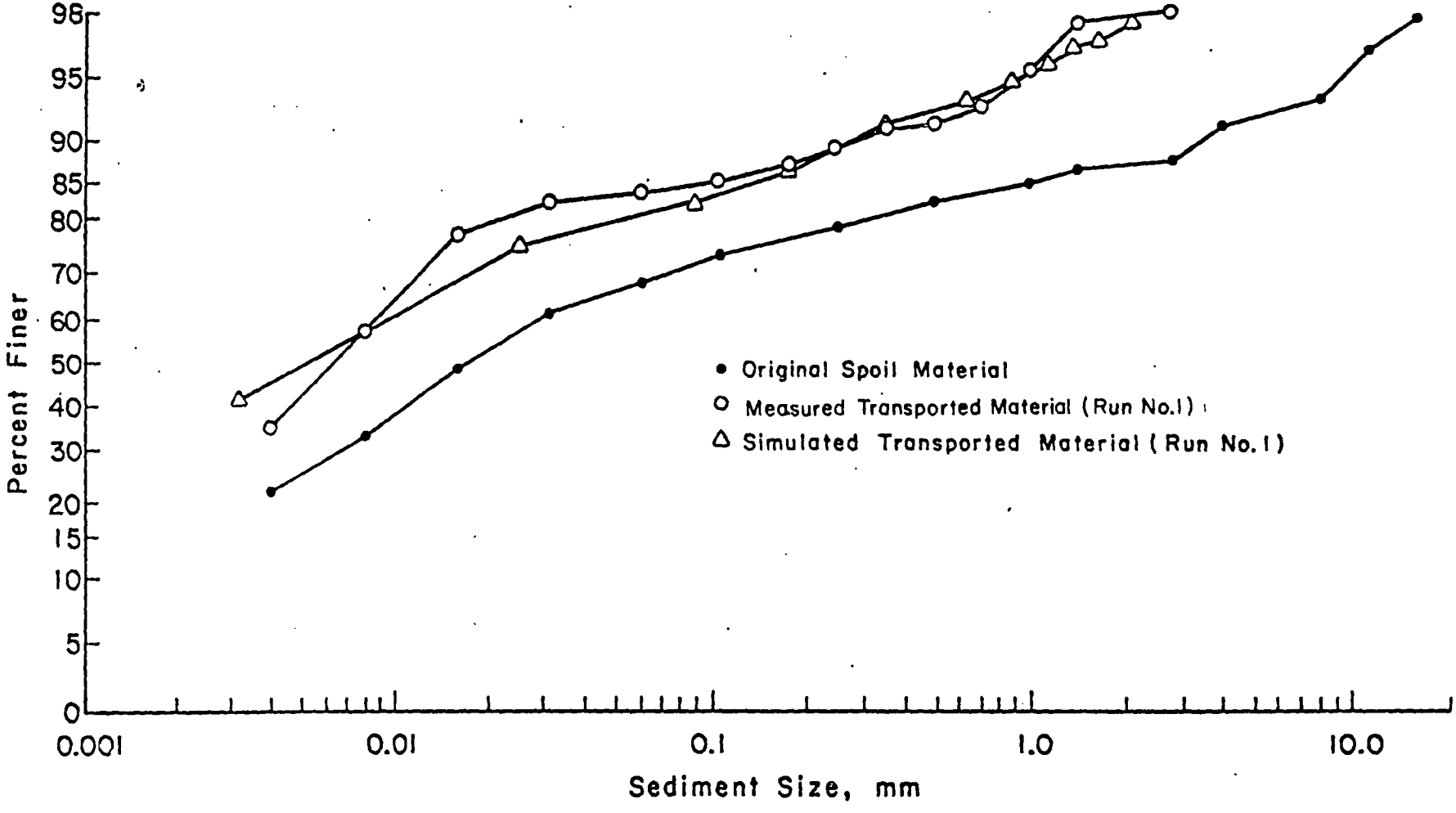

Figure 5.4. Sediment Size Distribution Curves.

VI. SUMMARY

This report presents a mathematical model for simulating on-side soil erosion. In general, the simulated results agree reasonably well with the observed data for both water and sediment yields. The simulated water hydrograph cannot reproduce the sharp corner as the peak flow is reached but overall it gives a good representation of the measured hydrograph. The simulated sediment hydrograph follows the shape of the water hydrograph and can only reproduce the average sediment discharge. The spike on the observed hydrograph is probably due to the concentration of flow into small rills which caused a locally high sediment transport rate. The simulated size distribution of the transported material agrees very well with the measured results. A computer listing is found in the Appendix which contains a listing and sample data and output as well as a description of important fortran symbols.

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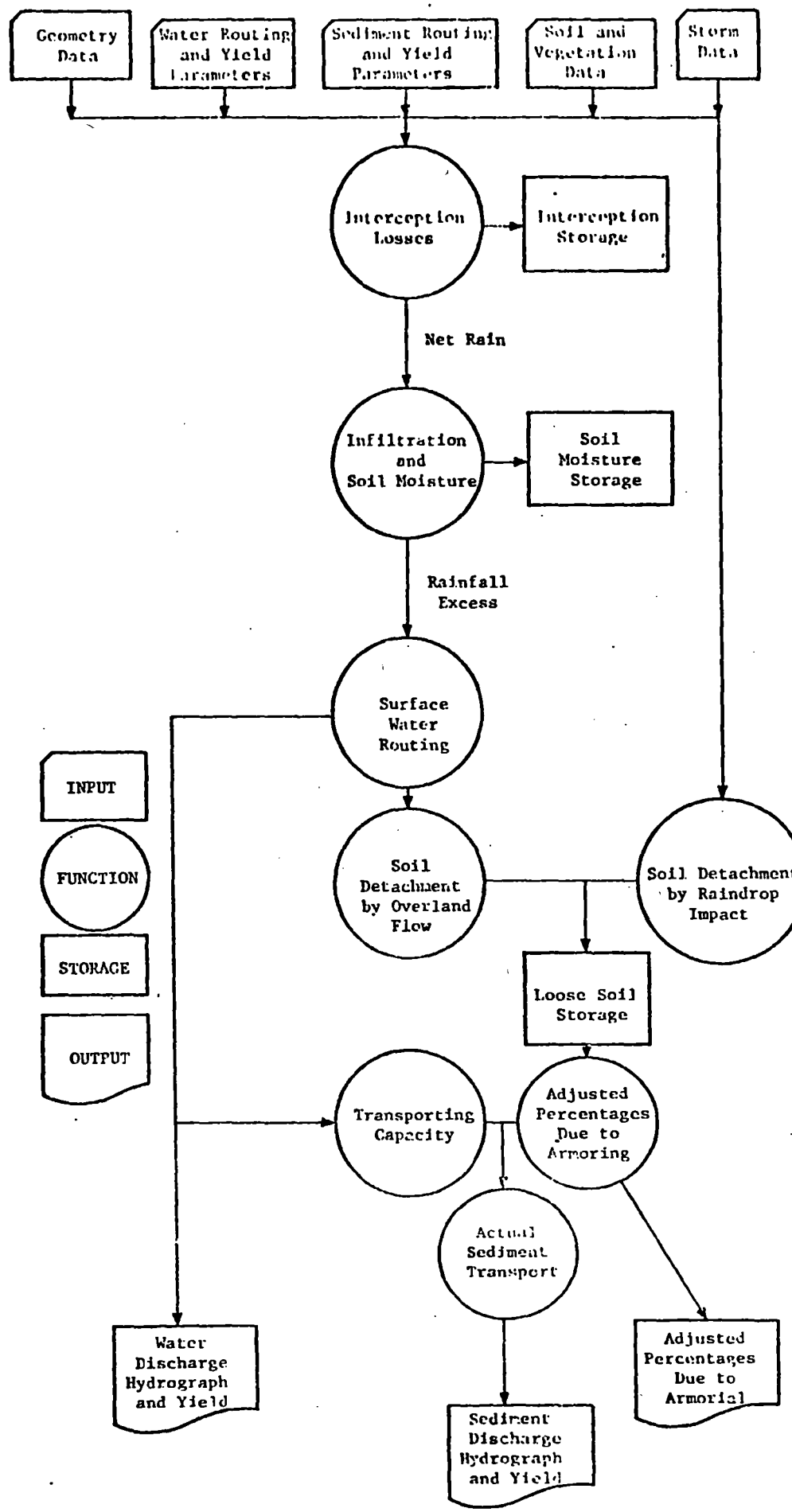
APPENDIX

APPENDIX

The appendix contains information on a computer program based on the material given in the text of this report. A flowchart shows how the various components are linked together. A brief description of each subroutine is given. The main fortran symbols are explained as well as the input requirements. A sample listing complete with data and output concludes the appendix (note that the input data is printed in the output of the computer listing).


Geometry Data
Water Routing and Yield Parameters
Sediment Routing and Yield Parameters
Soil and Vegetation Data
Storm Data
Interception Losses
Interception Storage
Net Rain
Infiltration and Soil Moisture
Soil Moisture Storage
Rainfall Excess
Surface Water Routing
INPUT
FUNCTION
STORAGE
OUTPUT
Soil Detachment by Overland Flow
Soil Detachment by Raindrop Impact
Loose Soil Storage
Transporting Capacity
Adjusted Percentages Due to Armoring
Actual Sediment Transport
Water Discharge Hydrograph and Yield
Adjusted Percentages Due to Armorial
Sediment Discharge Hydrograph and Yield

Brief Description of Program and Subroutines

1. PROGRAM SEDMT calls the subroutine which inputs the necessary data (DATA 1). Then it calls INITL which initializes the vectors and arrays. Finally, SEDMT calls ROUTE, the controlling subroutine.
2. DATA 1 reads the input data and prints it out.
3. INITL initializes the vectors and arrays used later in the computations.
4. ROUTE is the main controlling subroutine which calls the other subroutines in their proper order and stores the appropriate variables for later use. This subroutine also prints the final output.
5. INFIL determines the infiltration rate.
6. WROUT computes the unknown discharge at time n+1, space j+1.
7. FRICT determines the coefficient α and exponent β in the relation $y = \alpha\, q^{\beta}$.
8. DETCH determines the soil detachment due to raindrop inpact.
9. PERCT adjusts the percentage of soil in each size fraction due to armoring.
10. TRANSP uses the information computed in WROUT to determine the sediment transporting capacity of the flow.
11. CEASE sets the discharge and flow area to zero when the value ASUM is less than 10^{-7}.
12. POWER evaluates the J_1 and J_2 integrals in Einsteins sediment concentration profile.
13. SROUT determines the actual sediment transport concentration by comparing availability of material and transporting capacity of the flow.

LIST OF FORTRAN LABELS

FORTRAN LABEL	DEFINITION	SYMBOL IN THE TEXT
A	cross-sectional area of flow	A
AUP	cross-sectional area of flow at time n+1, space J	A_J^{n+1}
APUP	cross-sectional area of flow at time n, space J	A_J^n
APRE	cross-sectional area of flow at time n, space J+1	A_{J+1}^n
AE	cross-sectional area of flow at time n+1, space J+1	A_{J+1}^{n+1}
ALAT	cross-sectional area of flow corresponding to the lateral inflow	
ASUM	a value made up of known discharge and areas	Ω
AEST	a value made up of the unknown discharge which is iteratively adjusted until equal to ASUM	$f(r)$
AIM	coefficient in soil detachment by raindrop splash relation	a'_3
ADF	surface runoff detachment coefficient	D_f
ALPHA	average suction head across the wetting front	α'
ALP	coefficient in y vs. q relation	α
BET	exponent in y vs. q relation	β
BIM	exponent in soil detachment by raindrop splash relation	b'_3
CN	canopy cover density	C_c
CUP	sediment concentration at time n+1, space J	C_J^{n+1}
CPUP	sediment concentration at time n, space J	C_J^n
CPRE	sediment concentration at time n, space J+1	C_{J+1}^n

FORTRAN LABEL	DEFINITION	SYMBOL IN THE TEXT
CE	sediment concentration at time n+1, space J+1	C_{J+1}^{n+1}
RB	sediment concentration at time n+1, space J+1	C_{J+1}^{n+1}
DMB(M)	sediment sizes in each fraction	
D84	sediment size for which 84% of the sample is finer (by weight)	D_{84}
DELX	space increment	Δx
DT	time increment (min)	
DTS	time increment (sec)	Δt
DTN	time increment (sec) times the number of space increments	
DTX	ratio of $\Delta t/\Delta x$	θ
EGB(J)	change in loose soil storage	Δz
EPS	convergence criteria	ε
FGR	friction factor due to gram resistance $f = FGR/N_r$	f/N_r
FL	overall friction factor with low density vegetation, $f = FL/N_r$	K_L
FH	overall friction factor with high density vegetation, $f = FH/N_r$	K_H
FRA	infiltration rate	$\bar{f}$
FVB	particle fall velocity	V_s
GC	ground cover density	C_g
G(I,J)	sediment transport rate	q_s
GUP(J)	sediment transport rate at time n+1, space J	G_J^{n+1}
GPUP(J)	sediment transport rate at time n, space J	G_J^n
GPRE(J)	sediment transport rate at time n, space J+1	G_{J+1}^n

FORTRAN LABEL	DEFINITION	SYMBOL IN THE TEXT
GE(J)	sediment transport rate at time n+1, space J+1	G_{J+1}^{n+1}
GBL(J)	sediment transporting capacity	q_c
GELBS	total sediment transport rate	Σq_{si}
HYRAD	hydraulic radius	
IMAX	maximum number of iterations allowed in any iterative computation	
ITMAX(I)	number of time steps during storm	
ITCOM(I)	number of computational time steps	
MM	number of sediment size fractions	
NDX	number of space increments	
NSTOM	number of storms	
PBO(M)	original percentages of material in each size fraction	F_i
PB1(M)	adjusted percentages of material in each size fraction	F_{ai}
PERM	soil permeability	
PORB	one minus the porosity of the bed	$1-\phi$
QP(J)	discharge	q
QUP	discharge at time n+1, space J	q_J^{n+1}
QPUP	discharge at time n, space J	q_J^n
QPRE	discharge at time n, space J+1	q_{J+1}^n
QE	discharge at time n+1, space J+1	q_{J+1}^{n+1}
QLAT	lateral inflow (excess rainfall)	i_e
QW	discharge considering total width	
QYIELD	water yield	

FORTRAN LABEL	DEFINITION	SYMBOL IN THE TEXT
RAINI(I,J)	rainfall input	I
RCUM	cumulative rainfall	
RB(I,J)	sediment concentration at time n+1, space J+1	C_{J+1}^{n+1}
RMO	density of water	ρ
RN	flow Reynolds number	N_r
SB(J)	loose soil depth	
SDR	soil detachment rate due to raindrop impact	D_i
SEG	alph-numeric experiment identifier	
SINT	total interception losses	V_i
SMOIST(J)	soil moisture storage	
SLEN	slope length	
SLOP1	bedslope	S_o
SNU	kinematic viscosity of water	v
STORM(I)	alpha-numeric storm identifier	
SUMB	sum of loose soil depth for all size fractions	ΣZ_i
SUSP	suspended material transport rate	$q_{s\ell}$
SYIELD	sediment yield	
TAU	shear stress	τ
TTEM	difference between shear stress and critical tractive force	$\tau_o - \tau_c$
TIME	time	t
VMEAN	mean velocity	V
VOG	potential intercepted volume by ground cover	V_g
WEPER	wetted perimeter	P
WFA	space weight factor	a

FORTRAN LABEL	DEFINITION	SYMBOL IN THE TEXT
WFB	time weight factor	b
WHCV	canopy water holding capacity	V_c
WIDTH	width of soil plot	
XJ1, XJ2	integrals in suspended material transport rate defined by Einstein	J_1, J_2
ZBL(M)	loose soil depth in each size fraction	Z_i
ZSUM	sum of loose soil depths	ΣZ_i
ZMAXP	maximum penetration depth from raindrop impact	Z_M
ZWLS	depth of water plus loose soil	Z_W

INPUT CARDS

CARD NUMBER	COLUMNS	FORMAT	VARIABLE LABEL	CONTENTS
1	1-80	8A10	TITLE	PROBLEM TITLE
2	1-10	I10	NSTOM	Number of storms
	11-20	I10	NDX	Number of space increments
	21-30	I10	IMAX	Maximum number of iterative step
	31-40	I10	MM	Number of sediment size fractions
3	1-10	F10.3	WFA	Space weight factor
	11-20	F10.3	WFB	Time weight factor
	21-30	F10.3	DT	Time increment (min)
	31-40	F10.3	EPS	Convergence criteria
4	1-10	A10	SEG	Experiment identifier
	11-20	F10.3	SLEN	Slope length
	21-30	F10.3	WIDTH	Width of soil plot
	31-40	F10.3	SLOP1	Slope of soil plot
5	1-10	A10	STORM	Storm identifier
	11-20	I10	ITMAX	Number of time steps during storm
	21-30	I10	ITCOM	Number of computational time steps
6	1-10	F10.5	PERM	Soil permeability
	11-20	F10.5	ALPHA	Average suction head across wetting front
	21-30	F10.5	GC	Ground cover density
	31-40	F10.5	VOG	Potential intercepted volume by ground cover
	41-50	F10.5	CN	Canopy cover density
	51-60	F10.5	WHCV	Canopy water holding capacity

CARD NUMBER	COLUMNS	FORMAT	VARIABLE LABEL	CONTENTS
7-8	1-80	8F10.5	PBO(J)	Original size fraction percentage
9-10	1-80	8F10.5	DMB(J)	Sediment sizes (MM)
11	1-10	F10.5	FGR	Grain resistance factor, $f = \frac{FGR}{N_r}$
	11-20	F10.5	FL	Resistance factor with low density vegetation $f = \frac{FL}{N_r}$
	21-30	F10.5	FH	Resistance factor with high density vegetation, $f = \frac{FH}{N_r}$
	31-40	F10.5	SNU	Kinematic viscosity of water x 10^5 (Ft^2/sec)
12	1-10	F10.5	AIM	Coefficient in soil detachment by raindrop impact relation
	11-20	F10.5	BIM	Exponent in soil detachment by raindrop impact relation
	21-30	F10.5	ADF	Detachment coefficient by overland flow

```
SEDMT                                   CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      PROGRAM SEDMT (INPUT,OUTPUT)                                          SED   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                       SED   20
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                       SED   30
      COMMON /VAR3/ WFA,WFB,EPS,DT,DIS,DTN,DTX,DELX                         SED   40
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUSED   50
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                              SED   60
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV                   SED   70
      COMMON /VAR6/ STORM(10),ITMAX(10),ITCOM(10),RAINI(02,250),SMOIST(2SED   80
     150),SINT,RCUM                                                         SED   90
      COMMON /VAR7/ FGR,FL,FM,SNU,ALP,RET                                   SED  100
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBSED  110
     1(21,20),SUMH,D84                                                      SED  120
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                   SED  130
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                           SED  140
      CALL DATA1                                                            SED  150
      DO 101 KI=1,NSTOM                                                     SED  160
         CALL INITL (KI)                                                    SED  170
         CALL ROUTE (KI)                                                    SED  180
  101 CONTINUE                                                              SED  190
      STOP                                                                  SED  200
C                                                                           SED  210
      END                                                                   SED  220
```

```
DATA1                                   CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE DATA1                                                  DAT   10
      DIMENSION TITLE(8)                                                DAT   20
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                   DAT   30
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                   DAT   40
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                     DAT   50
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUDAT   60
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                          DAT   70
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV               DAT   80
      COMMON /VAR6/ STORM(10),ITMAX(10),ITCOM(10),RAINI(02,250),SMOIST(2DAT   90
     150),SINT,RCUM                                                     DAT  100
      COMMON /VAR7/ FGR,FL,FH,SNU,ALP,BET                               DAT  110
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBDAT  120
     1(21,20),SUMR,D84                                                  DAT  130
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT               DAT  140
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                       DAT  150
C                                                                       DAT  160
C     INPUT AND OUTPUT TITLE                                            DAT  170
C                                                                       DAT  180
      READ 103, TITLE                                                   DAT  190
      PRINT 120, TITLE                                                  DAT  200
C                                                                       DAT  210
C     INPUT GENERAL INFORMATION                                         DAT  220
C                                                                       DAT  230
      READ 104, NSTOM,NDX,IMAX,MM                                       DAT  240
      READ 105, WFA,WFB,DT,EPS                                          DAT  250
C                                                                       DAT  260
C     INPUT AND OUTPUT SOIL PLOT DATA                                   DAT  270
C                                                                       DAT  280
      READ 106, SEG,SLEN,WIDTH,SLOP1                                    DAT  290
      PRINT 107, SEG,SLEN,WIDTH,SLOP1                                   DAT  300
C                                                                       DAT  310
C     INPUT AND OUTPUT RAINFALL RECORDS                                 DAT  320
C                                                                       DAT  330
      READ 109, (STORM(I),ITMAX(I),ITCOM(I),I=1,NSTOM)                  DAT  340
      DO 101 I=1,NSTOM                                                  DAT  350
         K=ITMAX(I)                                                     DAT  360
C                                                                       DAT  370
C     IF RAINFALL IS NOT CONSTANT, RAINI(I,J) MUST BE READ IN           DAT  380
C                                                                       DAT  390
      DO 101 J=1,K                                                      DAT  400
         RAINI(I,J)=2.26                                                DAT  410
  101 CONTINUE                                                          DAT  420
      DO 102 I=1,NSTOM                                                  DAT  430
         TSTM=FLOAT(ITMAX(I))*DT                                        DAT  440
         TCOM=FLOAT(ITCOM(I))*DT                                        DAT  450
         PRINT 108, STORM(I),ITMAX(I),TSTM,ITCOM(I),TCOM                DAT  460
C                                                                       DAT  470
  102 CONTINUE                                                          DAT  480
C                                                                       DAT  490
C     OUTPUT GENERAL INFORMATION                                        DAT  500
C                                                                       DAT  510
      PRINT 110, NSTOM,NDX,IMAX,MM                                      DAT  520
      PRINT 111, WFA,WFB,DT,EPS                                         DAT  530
C                                                                       DAT  540
C     INPUT AND OUTPUT SOIL DATA AND PARAMETERS AND FLOW PARAMETERS     DAT  550
C                                                                       DAT  560
      READ 112, PERM,ALPHA,GC,VOG,CN,WHCV                               DAT  570
      PRINT 113, PERM,ALPHA,GC,VOG,CN,WHCV                              DAT  580
      READ 121, (PB0(J),J=1,MM)                                         DAT  590
```

```
DATA1                                CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      PRINT 114, (PB0(J),J=1,MM)                                          DAT  600
      READ 121, (DMB(I),I=1,MM)                                           DAT  610
      PRINT 115, (DMB(I),I=1,MM)                                          DAT  620
C                                                                         DAT  630
C     INPUT AND OUTPUT FLOW AND ROUTING PARAMETERS                        DAT  640
C                                                                         DAT  650
      READ 116, FGR,FL,FH,SNU                                             DAT  660
      PRINT 117, FGR,FL,FH,SNU                                            DAT  670
      READ 118, AIM,BIM,ADF                                               DAT  680
      PRINT 119, AIM,BIM,ADF                                              DAT  690
      RETURN                                                              DAT  700
C                                                                         DAT  710
  103 FORMAT (8A10)                                                       DAT  720
  104 FORMAT (4I10)                                                       DAT  730
  105 FORMAT (4F10.3)                                                     DAT  740
  106 FORMAT (A10,2F10.3,F10.5)                                           DAT  750
  107 FORMAT (10X,A10,5X, 13HSLOPE LENGTH=,F6.2,3X,  6HWIDTH=,F5.2,3X,    DAT  760
     16HSLOPE=,F8.5)                                                      DAT  770
  108 FORMAT (///10X,A10/10X, 45HRAINFALL DURATION(NUMBER OF TIME INCREMDAT  780
     1ENTS)=,I4,3X, 24H RAINFALL DURATION(MIN)=,F5.2/10X, 46HCOMPUTATIONDAT  790
     2 PERIOD(NUMBER OF TIME INCREMENTS)=,I4,3X, 24HCOMPUTATION PERIOD(MDAT  800
     3IN)=,F5.2///)                                                       DAT  810
  109 FORMAT (A10,2I10)                                                   DAT  820
  110 FORMAT (/,10X, 17HNUMBER OF STORMS=,I5/,10X, 27HNUMBER OF SPACE INDAT  830
     1CREMENTS=,I5/,10X, 34HMAXIMUM NUMBER OF ITERATIVE STEPS=,I5/,10X, DAT  840
     234HNUMBER OF SEDIMENT SIZE FRACTIONS=,I5///)                        DAT  850
  111 FORMAT (10X, 20HSPACE WEIGHT FACTOR=,F5.2,2X, 19HTIME WEIGHT FACTODAT  860
     1R=,F5.2/10X, 20HTIME INCREMENT(MIN)=,F6.3,2X, 21HCONVERGENCE CRITEDAT  870
     2RIA=,F6.3///)                                                       DAT  880
  112 FORMAT (6F10.5)                                                     DAT  890
  113 FORMAT (10X, 18HSOIL PERMEABILITY=,F8.4,2X, 13HSUCTION HEAD=,F6.3/DAT  900
     1,10X, 21HGROUND COVER DENSITY=,F5.2,2X, 43HPOTENTIAL INTERCEPTED VDAT  910
     2OLUME(GROUND COVER)=,F6.3/,10X, 21HCANOPY COVER DENSITY=,F5.2,2X, DAT  920
     330HCANOPY WATER HOLDING CAPACITY=,F6.3///)                          DAT  930
  114 FORMAT (50X, 25HSIZE FRACTION PERCENTAGES,/,6X,15F8.3)              DAT  940
  115 FORMAT (///50X, 20HSEDIMENT SIZES IN MM,/,8X,15F8.5)                DAT  950
  116 FORMAT (4F10.5)                                                     DAT  960
  117 FORMAT (///10X, 34HDARCY-WEISBACH FRICTION FACTOR, F=,18HA2/NR**B2DAT  970
     1, B2=1.0 /,10X, 32HGRAIN RESISTANCE FACTOR(A2=FGR)=,F5.2/,10X, 45HDAT  980
     2RESISTANCE FACTOR WITH LOW DENSITY VEGETATION,22H(A2=FL+(FH-FL)*GCDAT  990
     3*GC)=,F6.3/,10X, 54HRESISTANCE FACTOR WITH HIGH DENSITY VEGETATIONDAT 1000
     4(A2=FH)=,F7.1/,10X,37HKINEMATIC VISCOSITY OF WATER(X10**5)=,F5.2//DAT 1010
     5/)                                                                  DAT 1020
  118 FORMAT (3F10.5)                                                     DAT 1030
  119 FORMAT (10X, 50HCOEFFICIENT IN SOIL DETACHMENT BY RAINDROP IMPACT=DAT 1040
     1,F7.4/,10X, 47HEXPONENT IN SOIL DETACHMENT BY RAINDROP IMPACT=,F6.DAT 1050
     23/,10X, 38HSURFACE RUNOFF DETACHMENT COEFFICIENT=,F8.5///)          DAT 1060
  120 FORMAT (1H1/////50X,8A10///)                                        DAT 1070
  121 FORMAT (8F10.5)                                                     DAT 1080
C                                                                         DAT 1090
      END                                                                 DAT 1100
```

```
INITL                                   CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE INITL (KI)                                                INI   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                      INI   20
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                      INI   30
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                        INI   40
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUINI   50
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                             INI   60
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV                  INI   70
      COMMON /VAR6/ STORM(10),ITMAX(10),ITCOM(10),PAINI(02,250),SMOIST(2INI   80
     150),SINT,RCUM                                                        INI   90
      COMMON /VAR7/ FGR,FL,FH,SNU,ALP,BET                                  INI  100
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBINI  110
     1(21,20),SUMB,DB4                                                     INI  120
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                  INI  130
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                          INI  140
C                                                                          INI  150
C     INITIALIZE ENTIRE WATERSHED                                          INI  160
C                                                                          INI  170
      ITCOM1=ITCOM(KI)                                                     INI  180
      SNU=SNU/100000.                                                      INI  190
      DTS=DT*60.                                                           INI  200
      DTN=DTS*FLOAT(NDX)                                                   INI  210
      SUMP=0.                                                              INI  220
      SINT=GC*VOG*WHCV*CN                                                  INI  230
      RCUM=0.                                                              INI  240
      DO 101 M=1,MM                                                        INI  250
         PB1(M)=PB0(M)                                                     INI  260
         EGB(M)=0.                                                         INI  270
         SUMP=SUMP+0.245+0.0864/(0.1*DMB(M))**0.21                         INI  280
         GBC(M)=0.                                                         INI  290
         DMB(M)=DMB(M)/304.8                                               INI  300
         ZBL(M)=0.                                                         INI  310
  101 CONTINUE                                                             INI  320
      PORB=1.-SUMP/FLOAT(MM)                                               INI  330
      DO 102 I=1,ITCOM1                                                    INI  340
         SMOIST(I)=0.                                                      INI  350
  102 CONTINUE                                                             INI  360
      NDXX=NDX+1                                                           INI  370
      DO 103 J=1,NDXX                                                      INI  380
         A(J)=0.                                                           INI  390
         QP(J)=0.                                                          INI  400
         SLOP(J)=SLOP1                                                     INI  410
      DO 103 M=1,MM                                                        INI  420
         GUP(M)=0.                                                         INI  430
         GPRE(M)=0.                                                        INI  440
         GPUP(M)=0.                                                        INI  450
         CE(M)=0.                                                          INI  460
         GE(M)=0.                                                          INI  470
         CUP(M)=0.                                                         INI  480
         CPRE(M)=0.                                                        INI  490
         CPUP(M)=0.                                                        INI  500
         SB(J,M)=0.                                                        INI  510
         RB(J,M)=0.                                                        INI  520
  103 CONTINUE                                                             INI  530
      IF (MM.EQ.1) GO TO 106                                               INI  540
      SPER=0.                                                              INI  550
      DO 104 M=1,MM                                                        INI  560
         SPER=SPER+PB0(M)                                                  INI  570
         IF (SPER.GE.0.84) GO TO 105                                       INI  580
         SPER1=SPER                                                        INI  590
```

```
INITL                                    CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

  104 CONTINUE                                                          INI  600
  105 M1=M-1                                                            INI  610
      D84=(DMB(M)-DMB(M1))/(SPER-SPER1)*(0.84-SPER1)+DMB(M1)            INI  620
      GO TO 107                                                         INI  630
  106 D84=DMB(MM)                                                       INI  640
  107 CONTINUE                                                          INI  650
C                                                                       INI  660
      RETURN                                                            INI  670
C                                                                       INI  680
      END                                                               INI  690
```

```
ROUTE                                    CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE ROUTE (KI)                                                    ROU   10
      DIMENSION CCUP(20,20), GGUP(20,20), C(20,20), GW(20)                     ROU   20
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                          ROU   30
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                          ROU   40
      COMMON /VAR3/ WFA,WFB,EPS,DT,DIS,DTN,DTX,DELX                            ROU   50
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUROU   60
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                                 ROU   70
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV                      ROU   80
      COMMON /VAR6/ STORM(10),ITMAX(10),ITCOM(10),RAINI(02,250),SMOIST(2ROU   90
     150),SINT,RCUM                                                            ROU  100
      COMMON /VAR7/ FGR,FL,FH,SNU,ALP,BET                                      ROU  110
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBROU  120
     1(21,20),SUMB,DB4                                                         ROU  130
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                      ROU  140
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                              ROU  150
      ITCOM1=ITCOM(KI)                                                         ROU  160
      DTX=DTN/SLEN                                                             ROU  170
      DELX=SLEN/FLOAT(NDX)                                                     ROU  180
      NDXX=NDX+1                                                               ROU  190
      DO 101 IX=1,NDXX                                                         ROU  200
      DO 101 M=1,MM                                                            ROU  210
         C(IX,M)=0.                                                            ROU  220
         G(IX,M)=0.                                                            ROU  230
         CCUP(IX,M)=0.                                                         ROU  240
         GGUP(IX,M)=0.                                                         ROU  250
         GW(M)=0.                                                              ROU  260
  101 CONTINUE                                                                 ROU  270
C                                                                              ROU  280
      QYIELD=0.0                                                               ROU  290
      SYIELD=0.0                                                               ROU  300
      DO 114 IT=2,ITCOM1                                                       ROU  310
         AUP=0.                                                                ROU  320
         QUP=0.                                                                ROU  330
         QPUP=0.                                                               ROU  340
         ALAT=0.                                                               ROU  350
         QLAT=0.                                                               ROU  360
C                                                                              ROU  370
C     COMPUTE AT TIME IT (T+DT)                                                ROU  380
C     DETERMINATION OF RAINFALL INPUT                                          ROU  390
C                                                                              ROU  400
         IF (IT.GT.ITMAX(KI)) GO TO 102                                        ROU  410
         RAIN=RAINI(KI,1)                                                      ROU  420
         GO TO 103                                                             ROU  430
  102    RAIN=0.                                                               ROU  440
  103    CONTINUE                                                              ROU  450
C                                                                              ROU  460
C     DETERMINE RAINFALL EXCESS                                                ROU  470
C                                                                              ROU  480
C     COMPUTE THE INTERCEPTION LOSSES                                          ROU  490
C                                                                              ROU  500
         RCUM=RCUM+RAIN*DT                                                     ROU  510
         IF (RCUM.LE.SINT) GO TO 104                                           ROU  520
         RRAIN=(RCUM-SINT)/DT                                                  ROU  530
         RCUM=SINT                                                             ROU  540
         GO TO 105                                                             ROU  550
  104    RRAIN=0.                                                              ROU  560
  105    CONTINUE                                                              ROU  570
C                                                                              ROU  580
C     COMPUTE INFILTRATION LOSSES                                              ROU  590
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ROUTE                                    CDC 6400 FTN V3.0-P365 OPT=1   02/22/77

C                                                                              ROU  600
      CALL INFIL (ITCOM1,RRAIN,IT,FRA)                                         ROU  610
      RNET=RRAIN-FRA                                                           ROU  620
      IF (RNET.LT.0.) RNET=0.                                                  ROU  630
      ALAT=RNET*DTS/43200.                                                     ROU  640
      QLAT=ALAT/DTS                                                            ROU  650
      DO 111 J=2,NDXX                                                          ROU  660
         ZSUM=0.                                                               ROU  670
         SLP=SLOP(J)                                                           ROU  680
         QPRE=QP(J)                                                            ROU  690
C                                                                              ROU  700
C     DETERMINE THE COEFFICIENT AND THE EXPONENT IN A-Q RELATION               ROU  710
C                                                                              ROU  720
         CALL FRICT                                                            ROU  730
         AUP=ALP*QUP**BET                                                      ROU  740
         APUP=ALP*QPUP**BET                                                    ROU  750
         APRE=ALP*QPRE**BET                                                    ROU  760
         DO 106 M=1,MM                                                         ROU  770
            ZBL(M)=SB(J,M)                                                     ROU  780
            ZSUM=ZSUM+ZBL(M)                                                   ROU  790
            CUP(M)=CCUP(J-1,M)                                                 ROU  800
            GUP(M)=GGUP(J-1,M)                                                 ROU  810
            GPRE(M)=G(J,M)                                                     ROU  820
            GPUP(M)=G(J-1,M)                                                   ROU  830
            CPRE(M)=C(J,M)                                                     ROU  840
            CPUP(M)=C(J-1,M)                                                   ROU  850
  106    CONTINUE                                                              ROU  860
         CALL DETCH (J,MAIN)                                                   ROU  870
         ASUM=DTX*(QUP*(1.-WFA)-(QPRE-QPUP)*WFA)+ALAT+APRE*(1.-WFB)-(ROU  880
     1   AUP-APUP)*WFB                                                         ROU  890
         IF (ASUM.LE.1.0E-07) GO TO 108                                        ROU  900
C                                                                              ROU  910
C     DETERMINE QE, THE UNKNOWN DISCHARGE AT TIME N+1, SPACE J+1               ROU  920
C                                                                              ROU  930
         CALL WROUT                                                            ROU  940
C                                                                              ROU  950
C     DETERMINE ADJUSTED PERCENTAGES DUE TO ARMORING                           ROU  960
C                                                                              ROU  970
         CALL PERCT (J)                                                        ROU  980
C                                                                              ROU  990
C     DETERMINE SEDIMENT TRANSPORTING CAPACITY OF THE FLOW                     ROU 1000
C                                                                              ROU 1010
         CALL TRANSP (J)                                                       ROU 1020
         DO 107 M=1,MM                                                         ROU 1030
            CE(M)=RB(J,M)                                                      ROU 1040
            GE(M)=RB(J,M)*QE                                                   ROU 1050
            CCUP(J,M)=CE(M)                                                    ROU 1060
            GGUP(J,M)=GE(M)                                                    ROU 1070
  107    CONTINUE                                                              ROU 1080
C                                                                              ROU 1090
C     DETERMINE SEDIMENT CONCENTRATION                                         ROU 1100
C                                                                              ROU 1110
         CALL SROUT (J)                                                        ROU 1120
         GO TO 109                                                             ROU 1130
C                                                                              ROU 1140
C     SET DISCHARGE AND FLOW AREA TO ZERO WHEN ASUM .LE. 1.0E-07               ROU 1150
C                                                                              ROU 1160
  108    CALL CEASE (J)                                                        ROU 1170
  109    CONTINUE                                                              ROU 1180
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ROUTE                                   CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

            AUP=AE                                                          ROU 1190
            QUP=QE                                                          ROU 1200
            QPUP=QP(J)                                                      ROU 1210
            QP(J)=QE                                                        ROU 1220
            DO 110 M=1,MM                                                   ROU 1230
C                                                                           ROU 1240
C       SEDIMENT CONCENTRATION AT TIME N+1, SPACE J+1                       ROU 1250
C                                                                           ROU 1260
                CE(M)=RB(J,M)                                               ROU 1270
C                                                                           ROU 1280
C       SEDIMENT TRANSPORT RATE AT TIME N+1, SPACE J+1                      ROU 1290
C                                                                           ROU 1300
                GE(M)=RB(J,M)*QE                                            ROU 1310
                CCUP(J,M)=CE(M)                                             ROU 1320
                GGUP(J,M)=GE(M)                                             ROU 1330
                SB(J,M)=ZBL(M)+EGB(M)                                       ROU 1340
  110           CONTINUE                                                    ROU 1350
                TIME=FLOAT(IT)*DT                                           ROU 1360
  111       CONTINUE                                                        ROU 1370
            Qw=QE*WIDTH                                                     ROU 1380
            QYIELD=QYIELD+QE*WIDTH*DTS                                      ROU 1390
            GELBS=0.0                                                       ROU 1400
            DO 112 M=1,MM                                                   ROU 1410
               GELBS=GELBS+GE(M)*165.4*WIDTH                                ROU 1420
               GW(M)=GW(M)+GE(M)*WIDTH*DTS*165.4                            ROU 1430
  112       SYIELD=SYIELD+GE(M)*165.4*DTS*WIDTH                             ROU 1440
            PRINT 115, TIME,QW,GELBS,QYIELD,SYIELD                          ROU 1450
            PRINT 116, (PBL(M),M=1,MM)                                      ROU 1460
            PRINT 117, (GW(M),M=1,MM)                                       ROU 1470
            DO 113 II=2,NDXX                                                ROU 1480
            DO 113 M=1,MM                                                   ROU 1490
               G(II,M)=GGUP(II,M)                                           ROU 1500
               C(II,M)=CCUP(II,M)                                           ROU 1510
  113       CONTINUE                                                        ROU 1520
  114   CONTINUE                                                            ROU 1530
        RETURN                                                              ROU 1540
C                                                                           ROU 1550
  115   FORMAT (10X,  5HTIME=,F5.2,2X, 10HDISCHARGE=,E10.3,2X, 14HSEDIMENTROU 1560
       1 LOAD=,E10.3,2X, 19HWATER YIELD(CU FT)=,F5.2,2X, 20HSEDIMENT YIELDROU 1570
       2(LBS)=,F5.2//)                                                      ROU 1580
  116   FORMAT (50X, 34HADJUSTED SIZE FRACTION PERCENTAGES,/,10X,14F8.3)    ROU 1590
  117   FORMAT (50X, 31HSEDIMENT LOAD IN SIZE FRACTIONS,/,10X,14F8.3//)     ROU 1600
C                                                                           ROU 1610
        END                                                                 ROU 1620
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```
  INFIL                                    CDC 6400 FTN V3.0-P365 OPT=1   02/22/77

      SUBROUTINE INFIL (ITCOM1,RAIN,IT,FRA)                                  INF   10
      COMMON /VAR3/ WFA,WFB,EPS,DT,DIS,DIN,DTX,DELX                          INF   20
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV                    INF   30
      COMMON /VAR6/ STORM(10),ITMAX(10),ITCOM(10),RAINI(02,250),SMOIST(2INF   40
     150),SINT,RCUM                                                          INF   50
C                                                                            INF   60
C     THIS SUBROUTINE DETERMINES THE INFILTRATION RATE                       INF   70
C                                                                            INF   80
      FGA=SMOIST(IT)                                                         INF   90
      TBET=PERM*DT/60.                                                       INF  100
      DF=-0.5*(2.*FGA-TBET)+.5*SQRT((2.*FGA-TBET)**2+8.*TBET*(ALPHA+FGA)INF  110
     1)                                                                      INF  120
      FRA=DF*60./DT                                                          INF  130
      IF (FRA.GE.RAIN) GO TO 101                                             INF  140
      FGA=FGA+DF                                                             INF  150
      GO TO 102                                                              INF  160
  101 FGA=FGA+RAIN*DT/60.                                                    INF  170
      FRA=RAIN                                                               INF  180
  102 KX=IT+1                                                                INF  190
      IF (KX.GT.ITCOM1) RETURN                                               INF  200
      SMOIST(KX)=FGA                                                         INF  210
      RETURN                                                                 INF  220
C                                                                            INF  230
      END                                                                    INF  240
```

```
WROUT                                    CDC 6400 FTN V3.0-P365 OPT=1   02/22/77

      SUBROUTINE WROUT                                                    WRO   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                     WRO   20
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                     WRO   30
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                       WRO   40
      COMMON /VAR7/ FGR,FL,FM,SNU,ALP,BET                                 WRO   50
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                 WRO   60
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                         WRO   70
C                                                                         WRO   80
C     DETERMINE UNKNOWN DISCHARGE, QE                                     WRO   90
C     QE IS THE DISCHARGE AT TIME N+1, SPACE J+1                          WRO  100
C                                                                         WRO  110
      QAVE=0.5*(QUP+QPRE)                                                 WRO  120
      BEM=BET-1.                                                          WRO  130
      BEN=BEM-1.                                                          WRO  140
      ALBET=ALP*BET                                                       WRO  150
      ALBEM=ALP*BET*BEM                                                   WRO  160
      DTXA=DTX*ALP                                                        WRO  170
      ERROR=EPS*ASUM                                                      WRO  180
C                                                                         WRO  190
C     LINEAR SCHEME TO FIND THE FIRST APPROXIMATION                       WRO  200
C                                                                         WRO  210
      ITER=0                                                              WRO  220
      IF (QAVE.LE.1.0E-5) GO TO 101                                       WRO  230
      DAQ=ALBET*QAVE**BEM                                                 WRO  240
      QE=((1.-WFA)/DELX+ALP*BET*((QUP+QPRE)/2.)**(BET-1.)*(1.-WFA)/DTS)*WRO  250
     1*(-1.)*(QUP*(1.-WFA)/DELX-(QPRE-QPUP)*WFA/DELX-ALP*BET*((QUP+QPRE)WRO  260
     2/2.)**(BET-1.)*(-QPRE*(1.-WFA)/DTS+(QUP-QPUP)*WFA/DTS)+QLAT)        WRO  270
      IF (QE.LE.0.) GO TO 101                                             WRO  280
      GO TO 102                                                           WRO  290
  101 QE=ASUM/DTXA                                                        WRO  300
      IF (QE.LE.0.) QE=0.                                                 WRO  310
C                                                                         WRO  320
C     NONLINEAR SCHEME TO REFINE THE SOLUTION                             WRO  330
C                                                                         WRO  340
  102 ITER=ITER+1                                                         WRO  350
      AEST=DTX*(1.-WFA)*QE+ALP*(1.-WFB)*QE**BET                           WRO  360
      ADEV=ASUM-AEST                                                      WRO  370
      IF (ABS(ADEV).LE.ERROR) GO TO 107                                   WRO  380
      IF (ITER.LT.IMAX) GO TO 103                                         WRO  390
      PRINT 108, ITER                                                     WRO  400
      STOP                                                                WRO  410
  103 FDER=DTX*(1.-WFA)+ALBET*(1.-WFB)*QE**BEM                            WRO  420
      SDER=ALBEM*(1.-WFB)*QE**BEN                                         WRO  430
      BB=FDER/SDER                                                        WRO  440
      SC=2.*ADEV/SDER                                                     WRO  450
      STEM=BB*BB+SC                                                       WRO  460
      IF (STEM.GE.0.) GO TO 104                                           WRO  470
      QE=QE+ADEV/FDER                                                     WRO  480
      GO TO 102                                                           WRO  490
  104 STEM=SQRT(STEM)                                                     WRO  500
      IF (ADEV.GT.0.) GO TO 106                                           WRO  510
      ETEM=BB+STEM                                                        WRO  520
      QE=QE-ETEM                                                          WRO  530
      IF (QE.GT.0.) GO TO 102                                             WRO  540
  105 ETEM=0.5*ETEM                                                       WRO  550
      QE=QE+ETEM                                                          WRO  560
      IF (QE.GT.0.) GO TO 102                                             WRO  570
      GO TO 105                                                           WRO  580
  106 X1=QE-BB-STEM                                                       WRO  590
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 WROUT                          CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      X2=QE-BB*STEM                                              WRO  600
      AD1=ABS(ASUM-DTX*X1-ALP*X1**BET)                           WRO  610
      AD2=ABS(ASUM-DTX*X2-ALP*X2**BET)                           WRO  620
      QE=X1                                                      WRO  630
      IF (AD1.GT.AD2) QE=X2                                      WRO  640
      GO TO 102                                                  WRO  650
  107 RETURN                                                     WRO  660
C                                                                WRO  670
  108 FORMAT (10X,I10/)                                          WRO  680
C                                                                WRO  690
      END                                                        WRO  700
```

```
 FRICT                                  CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE FRICT                                                  FRC   10
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                   FRC   20
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV               FRC   30
      COMMON /VAR7/ FGR,FL,FH,SNU,ALP,BET                               FRC   40
C                                                                       FRC   50
C     THIS SUBROUTINE DETERMINES THE COEFFICIENT AND THE EXPONENT IN A-QFRC   60
C     RELATION                                                          FRC   70
C                                                                       FRC   80
      IF (GC.EQ.1.) GO TO 101                                           FRC   90
      A2=FL*(FH-FL)*GC*GC                                               FRC  100
      GO TO 102                                                         FRC  110
  101 A2=FH                                                             FRC  120
  102 CONTINUE                                                          FRC  130
      BET=1./3.                                                         FRC  140
      ALP=(A2*SNU/(257.6*SLP))**BET                                     FRC  150
      RETURN                                                            FRC  160
C                                                                       FRC  170
      END                                                               FRC  180
```

```
 DETCH                                  CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE DETCH (J,RAIN)                                         DET   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                   DET   20
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                     DET   30
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV               DET   40
      COMMON /VAR6/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBDET   50
     1(21,20),SUMH,D64                                                  DET   60
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT               DET   70
C                                                                       DET   80
C     DETERMINATION OF THE AMOUNT OF SOIL DETACHED BY RAINDROP IMPACT   DET   90
C                                                                       DET  100
      RIM=DT/60.*AIM*RAIN**BIM/12.                                      DET  110
      ZMAXP=6.69*RAIN**(.182)/304.8                                     DET  120
      DEPTH=A(J)                                                        DET  130
      ZWLS=DEPTH*ZSUM/PORB                                              DET  140
      IF (ZWLS.GE.ZMAXP) RETURN                                         DET  150
      PN=ZMAXP-ZWLS                                                     DET  160
      SDR=RIM*(1.-ZWLS/ZMAXP)                                           DET  170
      IF (SDR.LE.PN) GO TO 101                                          DET  180
      SDR=PN                                                            DET  190
  101 CONTINUE                                                          DET  200
      DO 102 M=1,MM                                                     DET  210
         ZBL(M)=ZBL(M)+SDR*PB0(M)*PORB                                  DET  220
  102 CONTINUE                                                          DET  230
      RETURN                                                            DET  240
C                                                                       DET  250
      END                                                               DET  260
```

```
PERCT                                   CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE PERCT (J)                                                  PER   10
      DIMENSION ST(20)                                                      PER   20
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                       PER   30
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBPER   40
     1(21,20),SUMB,D84                                                      PER   50
C                                                                           PER   60
C     DETERMINATION OF ADJUSTED PERCENTAGES DUE TO ARMORING                 PER   70
C                                                                           PER   80
      SUMB=0.                                                               PER   90
      DO 101 M=1,MM                                                         PER  100
         ST(M)=ZBL(M)                                                       PER  110
         SUMB=SUMB+ST(M)                                                    PER  120
  101 CONTINUE                                                            PER  130
      GMAX=PORB*D84                                                         PER  140
      IF (SUMB.GT.GMAX) GO TO 103                                           PER  150
      GDIF=GMAX-SUMB                                                        PER  160
      DO 102 M=1,MM                                                         PER  170
         ST(M)=ST(M)+PB0(M)*GDIF                                            PER  180
  102 CONTINUE                                                            PER  190
      SUMB=GMAX                                                             PER  200
  103 DO 104 M=1,MM                                                         PER  210
         PB1(M)=ST(M)/SUMB                                                  PER  220
  104 CONTINUE                                                            PER  230
      RETURN                                                                PER  240
C                                                                           PER  250
      END                                                                   PER  260
```

```
TRANSP                                  CDC 6400 FTN V3.0-P365 OPT=1  02/22/77

      SUBROUTINE TRANSP (J)                                                    TRA   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                          TRA   20
      COMMON /VAR2/ SEG,SLEN,WIDTH,SLOP1,SLOP(21),SLP                          TRA   30
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUTRA   40
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                                 TRA   50
      COMMON /VAR7/ FGR,FL,FM,SNU,ALP,BET                                      TRA   60
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBTRA   70
     1(21,20),SUMB,D84                                                         TRA   80
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                      TRA   90
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                              TRA  100
C                                                                              TRA  110
C     DETERMINATION OF FLOW CONDITIONS, SUCH AS HYDRAULIC DEPTH, MEAN          TRA  120
C     VELOCITY, AND BOUNDARY SHEAR STRESS                                      TRA  130
C                                                                              TRA  140
      AE=ALP*QE**BET                                                           TRA  150
      WEPER=1.                                                                 TRA  160
      HYRAD=AE                                                                 TRA  170
      RN=QE/(SNU*WEPER)                                                        TRA  180
      VMEAN=QE/AE                                                              TRA  190
      TAU=62.4*HYRAD*SLP                                                       TRA  200
      RHO=62.4/32.2                                                            TRA  210
      SV=SQRT(TAU/1.9379)                                                      TRA  220
      BMV=2.5*VMEAN/SV                                                         TRA  230
      TAO=RHO/8.*(FGR/RN**1.)**VMEAN*VMEAN                                     TRA  240
      DO 106 M=1,MM                                                            TRA  250
         TTEM=TAO-0.01*(2.65-1.)*62.4*DMB(M)                                   TRA  260
C                                                                              TRA  270
C     BED MATERIAL LOAD ROUTING                                                TRA  280
C                                                                              TRA  290
         IF (TTEM.LE.0.) GO TO 105                                             TRA  300
C                                                                              TRA  310
C     DETERMINATION OF RATIO OF SUSPENDED BED MATERIAL LOAD                    TRA  320
C                                                                              TRA  330
         IF (DMB(M).GT.0.0002) GO TO 101                                       TRA  340
         FVB=2.9517*DMB(M)**2/SNU                                              TRA  350
         GO TO 102                                                             TRA  360
  101    CONTINUE                                                              TRA  370
         FVB=(SQRT(36.064*DMB(M)**3+36.*SNU**2)-6.*SNU)/DMB(M)                 TRA  380
  102    ZR=FVB/(0.4*SV)                                                       TRA  390
         AR=2.*DMB(M)/HYRAD                                                    TRA  400
         IF (AR.GT.0.9) GO TO 103                                              TRA  410
         CALL POWER (ZR,AR,FJ,SJ,1.0E-2)                                       TRA  420
         P=AR**(ZR-1.)/(11.6*(1.-AR)**ZR)                                      TRA  430
         SUSP=P*(BMV*FJ+2.5*SJ)                                                TRA  440
         IF (SUSP.LT.0.) SUSP=0.                                               TRA  450
         GO TO 104                                                             TRA  460
  103    SUSP=0.                                                               TRA  470
C                                                                              TRA  480
C     DETERMINATION OF TRANSPORTING CAPACITY OF BED MATERIAL LOAD              TRA  490
C                                                                              TRA  500
  104    GBC(M)=(1+SUSP)*WEPER*8./SQRT(RHO)/(2.65*62.4-62.4)*TTEM**1.5         TRA  510
         RB(J,M)=GBC(M)*PB1(M)/QE                                              TRA  520
         GO TO 106                                                             TRA  530
  105    RB(J,M)=0.                                                            TRA  540
  106 CONTINUE                                                                 TRA  550
      RETURN                                                                   TRA  560
C                                                                              TRA  570
      END                                                                      TRA  580
```

CEASE CDC 6400 FTN V3.0-P365 OPT=1 02/22/77

```
      SUBROUTINE CEASE (J)                                                  CES   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                       CES   20
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                         CES   30
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUCES   40
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                              CES   50
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PCRB,ZSUM,EGB(20),ZBL(20),SRCES   60
     1(21,20),SUMA,D84                                                      CES   70
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                   CES   80
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                           CES   90
C                                                                           CES  100
C     END OF DISCHARGE WHEN ASUM .LE. 1.0E-07                               CES  110
C                                                                           CES  120
      QE=0.                                                                 CES  130
      AE=0.                                                                 CES  140
      DO 101 M=1,MM                                                         CES  150
         EGB(M)=DTX*GUP(M)*(1.-WFA)+(GPRE(M)-GPUP(M))*WFA*DTX+CPRE(M)*APCES  160
     1   RE*(1.-WFB)                                                        CES  170
  101 RB(J,M)=0.                                                            CES  180
      RETURN                                                                CES  190
C                                                                           CES  200
      END                                                                   CES  210
```

POWER CDC 6400 FTN V3.0-P365 OPT=1 02/22/77

```
      SUBROUTINE POWER (Z,A,XJ1,XJ2,CONV)                                   POW   10
C                                                                           POW   20
C     THIS SUBROUTINE EVALUATES J1 AND J2 INTEGRALS                         POW   30
C     NOTATIONS                                                             POW   40
C     XJ1 = VALUE OF J1 INTEGRAL                                            POW   50
C     XJ2 = VALUE OF J2 INTEGRAL                                            POW   60
C     N = ORDER OF APPROXIMATION + 1                                        POW   70
C     CONV = CONVERGENCE CRITERION                                          POW   80
C                                                                           POW   90
      N=1                                                                   POW  100
      XJ1=0.                                                                POW  110
      XJ2=0.                                                                POW  120
      ALG=ALOG(A)                                                           POW  130
      C=1.                                                                  POW  140
      D=-Z                                                                  POW  150
      E=D+1.                                                                POW  160
      FN=1.                                                                 POW  170
      AEX=A**E                                                              POW  180
      GO TO 102                                                             POW  190
  101 N=N+1                                                                 POW  200
      C=C*D/FN                                                              POW  210
      D=E                                                                   POW  220
      E=D+1.                                                                POW  230
      FN=FLOAT(N)                                                           POW  240
      AEX=A**E                                                              POW  250
  102 IF (ABS(E).LE.0.001) GO TO 103                                        POW  260
      XJ1=XJ1+C*(1.-AEX)/E                                                  POW  270
      XJ2=XJ2+C*((AEX-1.)/E**2-AEX*ALG/E)                                   POW  280
      GO TO 104                                                             POW  290
  103 XJ1=XJ1-C*ALG                                                         POW  300
      XJ2=XJ2-0.5*C*ALG**2                                                  POW  310
  104 IF (N.EQ.1) GO TO 105                                                 POW  320
      CJ1=ABS(1.-FJ1/XJ1)                                                   POW  330
      CJ2=ABS(1.-FJ2/XJ2)                                                   POW  340
      IF (CJ1.LE.CONV.AND.CJ2.LE.CONV) RETURN                               POW  350
  105 FJ1=XJ1                                                               POW  360
      FJ2=XJ2                                                               POW  370
      GO TO 101                                                             POW  380
C                                                                           POW  390
      END                                                                   POW  400
```

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SHOUT                                CDC 6400 FTN V3.0-P365 OPT=1   02/22/77

      SUBROUTINE SHOUT (J)                                                    SRO   10
      COMMON /VAR1/ NSTOM,NDX,IMAX,MM                                         SRO   20
      COMMON /VAR3/ WFA,WFB,EPS,DT,DTS,DTN,DTX,DELX                           SRO   30
      COMMON /VAR4/ G(21,20),GUP(20),GPUP(20),GPRE(20),GE(20),GBC(20),CUSRO   40
     1P(20),CPUP(20),CPRE(20),CE(20),RB(21,20)                                SRO   50
      COMMON /VAR5/ AIM,BIM,ADF,PERM,ALPHA,GC,VOG,CN,WHCV                     SRO   60
      COMMON /VAR8/ PB0(20),PB1(20),DMB(20),PORB,ZSUM,EGB(20),ZBL(20),SBSRO   70
     1(21,20),SUMB,DB4                                                        SRO   80
      COMMON /VAR9/ A(21),AUP,APUP,APRE,AE,ASUM,AEST,ALAT                     SRO   90
      COMMON /VAR10/ QP(21),QUP,QPUP,QPRE,QE,QLAT                             SRO  100
C                                                                             SRO  110
C     DETERMINATION OF SEDIMENT CONCENTRATION                                 SRO  120
C                                                                             SRO  130
C     CHECK THE AVAILABILITY OF BED MATERIAL LOAD                             SRO  140
C                                                                             SRO  150
      GSUP=0.                                                                 SRO  160
      GSPUP=0.                                                                SRO  170
      GSPRE=0.                                                                SRO  180
      GSE=0.                                                                  SRO  190
      DO 101 M=1,MM                                                           SRO  200
         GSUP=GSUP+GUP(M)                                                     SRO  210
         GSPUP=GSPUP+GPUP(M)                                                  SRO  220
         GSPRE=GSPRE+GPRE(M)                                                  SRO  230
         GSE=GSE+GE(M)                                                        SRO  240
  101 CONTINUE                                                                SRO  250
      IF (QUP.EQ.0.) GO TO 102                                                SRO  260
      CSUP=GSUP/QUP                                                           SRO  270
      GO TO 103                                                               SRO  280
  102 CSUP=0.                                                                 SRO  290
  103 IF (QPUP.EQ.0.) GO TO 104                                               SRO  300
      CSPUP=GSPUP/QPUP                                                        SRO  310
      GO TO 105                                                               SRO  320
  104 CSPUP=0.                                                                SRO  330
  105 IF (QPRE.EQ.0.) GO TO 106                                               SRO  340
      CSPRE=GSPRE/QPRE                                                        SRO  350
      GO TO 107                                                               SRO  360
  106 CSPRE=0.                                                                SRO  370
  107 IF (QE.EQ.0.) GO TO 108                                                 SRO  380
      CSE=GSE/QE                                                              SRO  390
      GO TO 109                                                               SRO  400
  108 CSE=0.                                                                  SRO  410
  109 CONTINUE                                                                SRO  420
      ESUM=-DTX*((GSE-GSUP)*(1.-WFA)+(GSPRE-GSPUP)*WFA)-((CSE*AE-CSPRE*ASRO  430
     1PRE)*(1.-WFB)+(CSUP*AUP-CSPUP*APUP)*WFB)                                SRO  440
      IF (ESUM.GE.0.) GO TO 110                                               SRO  450
      EBTEM=ESUM+SUMB                                                         SRO  460
      IF (EBTEM.GE.0.) GO TO 110                                              SRO  470
      DEP=-ADF*EBTEM                                                          SRO  480
      GO TO 111                                                               SRO  490
  110 DEP=0.                                                                  SRO  500
  111 CONTINUE                                                                SRO  510
C                                                                             SPO  520
C     DETERMINATION OF AVAILABILITY FOR NEXT TIME STEP                        SRO  530
C                                                                             SRO  540
      DO 112 M=1,MM                                                           SRO  550
         ZBL(M)=ZBL(M)+DEP*PB0(M)                                             SRO  560
  112 CONTINUE                                                                SPO  570
      DO 113 M=1,MM                                                           SRO  580
         EGB(M)=-DTX*((GE(M)-GUP(M))*(1.-WFA)+(GPRE(M)-GPUP(M))*WFA)-((CSRO  590
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SROUT                                          CDC 6400 FTN V3.0-P365 OPT=1   02/22/77

     1   E(M)*AE-CPRE(M)*APRE)*(1.-WFB)+(CUP(M)*AUP-CPUP(M)*APUP)*WFB)   SRO   600
         IF (EGB(M).GE.0.) GO TO 113                                      SRO   610
         EBTEM=EGB(M)+ZBL(M)                                              SRO   620
         IF (EBTEM.GE.0.) GO TO 113                                       SRO   630
         RB(J,M)=(CPRE(M)*APRE*(1.-WFB)-(CUP(M)*AUP-CPUP(M)*APUP)*WFB-DTSRO   640
     1   X*(-GUP(M)*(1.-WFA)+(GPRE(M)-GPUP(M))*WFA)+ZBL(M))/(AE*(1.-WFB)SRO   650
     2   +DTX*QE*(1.-WFA))                                                SRO   660
         IF (RB(J,M).LE.0.) RB(J,M)=0.0                                   SRO   670
         EGR(M)=-ZBL(M)                                                   SRO   680
 113 CONTINUE                                                             SRO   690
     RETURN                                                               SRO   700
C                                                                         SRO   710
     END                                                                  SRO   720
```

VANLIEW'S MINE SPOIL DATA

VANLIEW1 SLOPE LENGTH= 31.29 WIDTH=12.69 SLOPE= .07000

TEST1
RAINFALL DURATION(NUMBER OF TIME INCREMENTS)= 100 RAINFALL DURATION(MIN)=50.00
COMPUTATION PERIOD(NUMBER OF TIME INCREMENTS)= 125 COMPUTATION PERIOD(MIN)=62.50

NUMBER OF STORMS= 1
NUMBER OF SPACE INCREMENTS= 5
MAXIMUM NUMBER OF ITERATIVE STEPS= 100
NUMBER OF SEDIMENT SIZE FRACTIONS= 14

SPACE WEIGHT FACTOR= .50 TIME WEIGHT FACTOR= .50
TIME INCREMENT(MIN)= .500 CONVERGENCE CRITERIA= .010

SOIL PERMEABILITY= .8438 SUCTION HEAD= .130
GROUND COVER DENSITY= 0.00 POTENTIAL INTERCEPTED VOLUME(GROUND COVER)= 0.000
CANOPY COVER DENSITY= 0.00 CANOPY WATER HOLDING CAPACITY= 0.000

SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT SIZES IN MM

.00063	.00316	.02500	.08840	.17680	.35360	.61240	.88600	1.11800	1.36930	1.62020	2.09170	3.16230	8.00000

DARCY-WEISBACH FRICTION FACTOR, F=A2/NR**N2, N2=1.0
BRAIN RESISTANCE FACTOR(A2=FSRI)=50.00
RESISTANCE FACTOR WITH LOW DENSITY VEGETATION(A2=FL+(FH-FL)*GC*GC)=50.000
RESISTANCE FACTOR WITH HIGH DENSITY VEGETATION(A2=FH)=40000.0
KINEMATIC VISCOSITY OF WATER(X10**5)= 1.05

COEFFICIENT IN SOIL DETACHMENT BY RAINDROP IMPACT= .0001
EXPONENT IN SOIL DETACHMENT BY RAINDROP IMPACT= 2.000
SURFACE RUNOFF DETACHMENT COEFFICIENT= .00055

TIME= 1.00 DISCHARGE= 0. SEDIMENT LOAD= 0. WATER YIELD(CU FT)= 0.00 SEDIMENT YIELD(LBS)= 0.00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 1.50 DISCHARGE= 0. SEDIMENT LOAD= 0. WATER YIELD(CU FT)= 0.00 SEDIMENT YIELD(LBS)= 0.00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 2.00 DISCHARGE= 0. SEDIMENT LOAD= 0. WATER YIELD(CU FT)= 0.00 SEDIMENT YIELD(LBS)= 0.00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 2.50 DISCHARGE= 0. SEDIMENT LOAD= 0. WATER YIELD(CU FT)= 0.00 SEDIMENT YIELD(LBS)= 0.00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 3.00 DISCHARGE= .155E-05 SEDIMENT LOAD= .257E-05 WATER YIELD(CU FT)= .00 SEDIMENT YIELD(LBS)= .00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.000	.000	.000	.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 3.50 DISCHARGE= .495E-04 SEDIMENT LOAD= .252E-04 WATER YIELD(CU FT)= .00 SEDIMENT YIELD(LBS)= .00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.000	.000	.000	.000	.000	.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 4.00 DISCHARGE= .103E-03 SEDIMENT LOAD= .218E-04 WATER YIELD(CU FT)= .00 SEDIMENT YIELD(LBS)= .00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.000	.001	.001	.000	.000	.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TIME= 4.50 DISCHARGE= .437E-03 SEDIMENT LOAD= .782E-04 WATER YIELD(CU FT)= .02 SEDIMENT YIELD(LBS)= .00

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.000	.001	.001	.000	.000	.000	.000	.000	.000	0.000	0.000	0.000	0.000	0.000

TIME= 5.00 DISCHARGE= .167E-02 SEDIMENT LOAD= .391E-03 WATER YIELD(CU FT)= .07 SEDIMENT YIELD(LBS)= .02

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.001	.005	.006	.001	.001	.001	.000	.000	.000	.000	.000	0.000	0.000	0.000

TIME= 5.50 DISCHARGE= .350E-02 SEDIMENT LOAD= .858E-03 WATER YIELD(CU FT)= .17 SEDIMENT YIELD(LBS)= .04

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.003	.014	.015	.003	.002	.002	.001	.001	.000	.000	.000	.000	0.000	0.000

TIME= 6.00 DISCHARGE= .726E-02 SEDIMENT LOAD= .283E-02 WATER YIELD(CU FT)= .39 SEDIMENT YIELD(LBS)= .13

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.009	.044	.046	.009	.006	.006	.003	.002	.001	.001	.001	.001	.001	0.000

TIME= 6.50 DISCHARGE= .732E-02 SEDIMENT LOAD= .364E-02 WATER YIELD(CU FT)= .61 SEDIMENT YIELD(LBS)= .24

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.090

SEDIMENT LOAD IN SIZE FRACTIONS

.017	.081	.084	.016	.011	.011	.005	.003	.003	.001	.001	.001	.003	0.000

TIME= 7.00 DISCHARGE= .735E-02 SEDIMENT LOAD= .360E-02 WATER YIELD(CU FT)= .83 SEDIMENT YIELD(LBS)= .34

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.091

SEDIMENT LOAD IN SIZE FRACTIONS

.025	.110	.120	.023	.016	.016	.007	.005	.004	.002	.002	.002	.00[illegible]	0.000

TIME= 7.50 DISCHARGE= .816E-02 SEDIMENT LOAD= .425E-02 WATER YIELD(CU FT)= 1.08 SEDIMENT YIELD(LBS)= .47

ADJUSTED SIZE FRACTION PERCENTAGES

.065	.305	.310	.060	.040	.040	.018	.012	.010	.005	.005	.005	.035	.091

SEDIMENT LOAD IN SIZE FRACTIONS

.034	.162	.164	.032	.021	.021	.010	.006	.005	.003	.003	.003	.008	0.000

TIME=60.00 DISCHARGE= .132E-03 SEDIMENT LOAD= .395E-04 WATER YIELD(CU FT)=29.74 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.208	5.294	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

TIME=60.50 DISCHARGE= .125E-03 SEDIMENT LOAD= .367E-04 WATER YIELD(CU FT)=29.74 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.209	5.294	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

TIME=61.00 DISCHARGE= .118E-03 SEDIMENT LOAD= .342E-04 WATER YIELD(CU FT)=29.75 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.209	5.295	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

TIME=61.50 DISCHARGE= .113E-03 SEDIMENT LOAD= .320E-04 WATER YIELD(CU FT)=29.75 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.210	5.295	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

TIME=62.00 DISCHARGE= .106E-03 SEDIMENT LOAD= .293E-04 WATER YIELD(CU FT)=29.75 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.210	5.295	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

TIME=62.50 DISCHARGE= .101E-03 SEDIMENT LOAD= .275E-04 WATER YIELD(CU FT)=29.76 SEDIMENT YIELD(LBS)=15.35

ADJUSTED SIZE FRACTION PERCENTAGES

.063	.294	.299	.058	.039	.039	.017	.012	.010	.005	.005	.005	.034	.122

SEDIMENT LOAD IN SIZE FRACTIONS

1.110	5.210	5.295	1.025	.683	.683	.307	.205	.171	.085	.085	.085	.407	0.000

AD-33 Bookplate
(1-68)

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